G84-690

Estimating Soil Moisture by Appearance and Feel

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> This NebGuide provides a guide to determining how much moisture is in different soil textures, and where it is located in the soil profile.

Evaluating soil moisture is one of the most important management tools that an irrigator has. Determining the status of the soil moisture reservoir guides the decision of not only how much to irrigate, but also when to irrigate. The "appearance and feel" method of monitoring soil moisture using a soil probe is still a valid procedure no matter how sophisticated the irrigation scheduling system. A measurement of soil moisture is essential to update knowledge of the need for and timing of irrigation, and the "appearance and feel" method can be used to obtain that information.

In addition to indicating how much moisture is in the soil, this method also reveals where that moisture is located in the profile. This information is important to the irrigator as well as the dryland farmer. The depth of water penetration from irrigation or rainfall is useful in planning and making management decisions. For example, problem areas with compacted soil layers that restrict water penetration may be detected with the soil probe.

Soil texture, the relative amounts of sand, silt or clay contained in a soil, is an indicator of the amount of water a soil will hold. Available water capacity is the maximum amount of moisture the soil will hold that plants can use. The values of available water for four basic textural classes are given in *Table 1*.

The textural classification of a soil is important not only for knowing how much water potentially can be held for crop use, but also for visual inspection. Different soil types respond differently to the methods described in this NebGuide, which is one of the keys to making the soil moisture determination. The county soil survey, which can be obtained through your Cooperative Extension Service office or the Soil Conservation Service, includes discussions on soil texture and available water capacity of your soils.

Table 1. Available water capacity for soils.

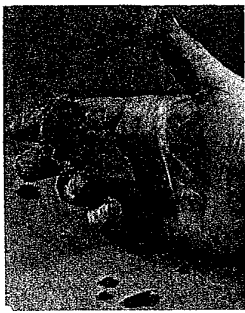| Soil texture	Available water inches/foot
Fine sand *or* loamy sand	1.0 to 1.1
Sandy loam	1.4
Loam *or* silt loam	2.0 to 2.5
Silty clay loam *or* clay loam	1.8
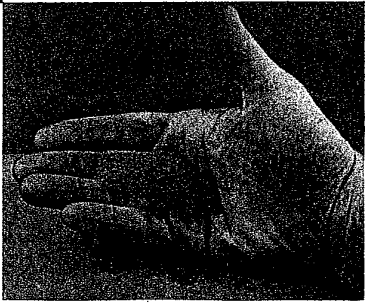
Sampling and Evaluation Procedures

A soil probe, soil auger, or spade can be used to extract a soil sample. Evaluate the soil moisture at one foot intervals from the surface to the bottom of the active root zone. The active root zone for most irrigated crops is approximately 3 feet* deep. When checking for water penetration or soil moisture for dryland crops, probe to the depth of 4 to 5 feet.

To begin learning the appearance and feel of your soil at particular moisture contents, start early in the spring one or two days after a heavy rain. At this point the soil moisture level should be near field capacity, or holding 100 percent of the water that it can naturally retain. Likewise, probe the soil at the end of the growing season when the profile is likely to be dry. Knowing the appearance and feel of your soil at the wet and dry ends of the spectrum will help make determinations during the midseason. In addition, use the pictures on pages 2 and 3 of the three soil types at four different moisture contents as a guide to making your estimations.
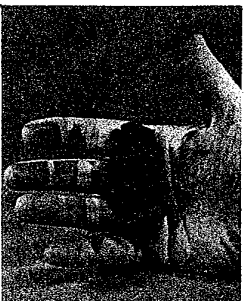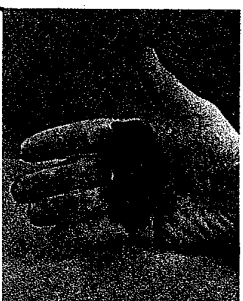
The number and location of sampling sites depends on both the uniformity of the soils in the field and the irrigation procedures. Check problem areas in the field in addition to the starting and stopping areas of your particular irrigation system. Sample a minimum of four sites in different parts of the field.

*To convert to metrics, multiply feet by 0.3 to find meters; inches by 2.54 to find centimeters.

Available Soil Moisture Remaining	Sand and Loamy Sand	
Oven dry	Dry, loose, single grained, flows through fingers	
0 Percent (wilting point)	Will not form a ball. Crumbs into individual grains	
50 Percent	Tends to ball under pressure but seldom holds together	
100 Percent (Field capacity)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand	Forms ball which crumbles when pressed between thumb and forefingers

Procedure:
1. Determine texture of soil.
2. Squeeze small handful of soil firmly.
3. Observe the condition of the ball and your hand.
4. Attempt to form a ribbon of the soil between your thumb and forefinger.
5. Observe what happens.

Moisture is Available for Crops

mications Specialist, North Platte Station)

Loam and Silt Loam	Silty Clay Loam and Clay Loam
Powdery dry, sometimes slightly crusted but easily broken down into powdery condition	Hard, baked, cracked, sometimes has loose crumbs on surface
Crumbly but holds together from pressure	Somewhat crumbly, but holds together from pressure
Forms a ball, will sometimes slick slightly under pressure	Forms a ball, ribbons out between thumb and forefinger
Upon squeezing, no free water appears on soil but wet outline of ball is left on hand / Forms a ball, is very pliable, slicks readily	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand / Easily ribbons out between fingers, has slick feeling

When using a soil probe to extract the samples, the following procedures will make the job easier.

a. Scrape a clean, level area on the soil surface before inserting the probe.

b. Insert the probe to the desired depth (at one foot increments) and turn the probe once clockwise before pulling it back to the surface.

c. After inspecting the soil, remove all of the soil from the tube, including the tip. A fitted dowel may help. Soil left in the tip may tend to compact the next sample.

d. Clean the probe after each use to prevent rust and hard caked soil.

e. Replace or sharpen the tip as needed.

The techniques for estimating soil moisture are shown on pages 2 and 3.

Calculating Soil Moisture Status

After estimating the soil moisture, the amount of water in the soil reservoir can be calculated using *Table 1*. The following example illustrates the calculation:

1. Soil: Silt loam (from soil survey classification).

2. Available moisture at field capacity = 2.4 inches/foot.

3. Current soil moisture status = 50% available soil moisture remaining (from appearance and feel method evaluation).

4. Amount of soil in sample = 1 foot.

5. Available moisture remaining in sample = (.50) x (2.4 inches/foot) x (1 foot) = 1.2 inches.

Complete this calculation for each sample extracted. The total of the moisture remaining for all samples is the water still available in the sampled profile.

For more information on using this remaining available moisture for scheduling irrigations, refer to Extension Circulars EC 79-723 ("Irrigation Scheduling Using Soil Moisture Blocks in Deep Soil") or EC 80-724 ("Irrigation Scheduling Using Tensiometers and Evapotranspiration on Deep Sandy Soils").

IRRIGATION WATER MANAGEMENT

GENERAL

Irrigation water management is the act of timing and regulating irrigation water applications in a way that will satisfy the water requirement of the crop without the waste of water, soil, or plant nutrients. It means applying water according to crop needs in amounts that can be held in the soil available to crops and at rates consistent with the intake characteristics of the soil and the erosion hazard of the site.

IRRIGATION TIMING (Scheduling)

1. Determining when and how much to apply.

    a. The determination of when and how much to apply requires a knowledge of the available water capacity (AWC) of the soil, the management allowed depletion (MAD) or plant stress level for the specified crop, the crop peak consumptive use, crop rooting depth, and the critical periods in the growing season when the crop should not be stressed.

    b. One of the most effective way of determining when and how much water to apply is to measure or estimate the soil water content. Measurements should be made in that part of the soil from which plant roots extract their moisture and according to the moisture-extraction pattern of the particular crop. There are other methods being developed to determine when to irrigate but measuring soil moisture is the most effective method in use now.

        (1) In uniformly textured soils, one measurement should be made at the midpoint in each quarter of the root zone. For shallow rooted crops (maximum 3 foot deep root zones), it is probably desirable to take three measurements. As an example, in a 24-inch root zone, measurements may be taken from the 6-, 12-, and 18-inch depth.

        (2) In stratified soils, one measurement should be taken from each textural strata. It may not be necessary to take a measurement in very thin layers when this thin layer can be lumped with another layer for estimating soil moisture. Where the strata is thick a sample should be taken in 1-foot increments as a minimum. Thickness of the strata should be noted.

        (3) The crop root depth for annual crops changes through the early part of the growing season. Measurements should be made in the soil profile according to the current depth of the majority of the crop roots.

    c. The selection of soil moisture measurement stations is important. The stations should be located so that average soil moisture conditions in the root zone of the crop are measured. Excess water from leaks in pipe joints, low spots in a field, etc., should not be allowed to come

in contact with the measurement station. High spots with excessive water runoff should not be chosen because the soil profile in this area will not represent average root zone conditions. Average soil and slope conditions in the field should be represented in station locations. Measurements should be made at other locations as indicated by any critical condition in the soil, such as an area that dries out first. It is a good practice to have at least two measurement stations in each critical area and two or three stations in areas that are typical of the field. This information provides direction for adjusting the amount and frequency of irrigation for different parts of the field or for different periods in the growing season.

(1) Location in relation to plants. (a) Row crops - locate in the crop row as near the plants as possible;

(b) Mature trees - located 4 to 6 feet from the trunk but inside the tree drip line; and

(c) Crops with complete cover such as alfalfa and grains - locate in representative soil and slope areas of the field.

(2) Location in relation to irrigation systems. (a) Lateral move sprinklers such as side roll or hand move aluminum pipe - locate measurement stations halfway between adjacent sprinkler heads and 10 to 15 feet from the lateral;

(b) Center pivot sprinklers - locate measurement stations at about two-thirds of the total lateral distance from the pivot;

(c) Solid set sprinklers - locate measurement stations where the diagonals from four adjacent sprinkler heads cross.

(d) Trickle systems - locate in the wetted ball in the root zone; and

(e) Furrows and corrugations - measurement stations should be located in about the center of the furrow or corrugation bed near the plants.

(3) Location in field or surface irrigation systems. (a) One measurement station should be located 50 to 100 feet downstream from the beginning of the irrigation run near the side of the field where irrigation is to be started. This avoids seepage bias from the head ditch or pipeline and provides a reference point for starting the irrigation cycle.

(b) An additional station should be located near the other side of the field at 50 to 100 feet downstream from the beginning of the irrigation run to be sure the field is being covered fast enough to maintain an adequate moisture level.

(c)   One or two additional stations should be located 50 to 100 feet upstream from the end of the irrigation run. These stations should be far enough upstream so they are unaffected by standing tailwater. These stations measure minimum water applications because they generally obtain the least amount of water at the end of the run.

(d)   One or two additional stations should be located close to the center of the irrigation run.

(4)   Location in field for sprinkler or trickle irrigation systems - sprinkler and trickle irrigation systems lose pressure down the lateral due to friction loss throughout the lateral so sprinkler heads farthest from the main lines put out the least irrigation water. To check adequacy of irrigations, locate measurement stations as follows:

(a)   50 to 100 feet downstream from the beginning of the lateral.

(b)   50 to 100 feet upstream from the distal end of the lateral.

(c)   At least one measurement close to the center of the lateral. For laterals 1,320 feet or less in length, one center measurement should be adequate. For laterals 1,320 feet to 2,640 feet long, locate two measurement stations at the one-third points along the lateral.

d.   Measurements should be taken weekly in spring and fall and more frequently during the hot weather and critical growth periods of the crop. The irrigator may be able to reduce the frequency of readings after he has become familiar with the pattern of moisture depletion. To accurately predict moisture levels, measurements should be taken and recorded regularly, regardless of the time of year or the stage of crop growth. Comparison of yearly records with crop yields helps the irrigator to improve his management of the irrigation system.

e.   The following procedure can be used to predict when and how much to apply using soil water content (SWC) measurements. This procedure is illustrated in Paragraph 1.k.

(1)   Establish the available water capacity (AWC) of the soil for the site. Plot this value on graph paper (rectangular grid-time series-1 year by days x 250 divisions) similar to Figure 1.1.

(2)   Set the management allowed deficiency (MAD) level or level of plant stress. Management allowed deficiency (MAD) levels are given in the Crops section.

(3)   Determine the soil water content (SWC) at the selected MAD and show on graph.

$$SWC_{MAD} \text{ (inches)} = \frac{AWC \text{ (inches)} \times (MAD \text{ (percent)})}{100}$$

(4) To start use of the graph a SWC measurement is made. This value is plotted on the graph for the date the measurement was made. It is desirable to start the graph when the soil profile is full. After an irrigation or rainfall a check should be made to verify that the profile is full. The date of the irrigation or rain should be noted on the graph.

(5) The time when measurements are made will depend on the stage of crop growth, climatic conditions, and AWC of the soil.

(a) For a deep rooted crop in a coarse textured soil, a check should be made within 3 or 4 days after an irrigation that fills the root zone to the desired depth, in medium textured soils, 5 or 6 days, and for fine textured soils, about 8 to 10 days after irrigation or rainfall.

(b) At shallower root depths, the check after irrigation should be made sooner. The time period will depend on the AWC and root depth of the specific crop.

(c) Plot the SWC against measurements for the date the measurements were made.

(6) Make additional SWC checks as necessary.

(7) Draw a line through the points of the first and second check and project it to the MAD line. The point where the line intersects the MAD line is the approximate date that the next irrigation should take place. A couple of days before that date of irrigation, a check should be made to verify the date.

(8) The amount of water to be applied (F^n) can be determined as follows.

(a) If the date of irrigation is approximately the same (2 or 3 days) as the projected date then use the SWC at the MAD level.

(b) When the irrigation occurs earlier or later than the projected date then make an estimate of SWC for that irrigation date. This is done by finding the irrigation date on the projected line, then going to the left and intersecting the vertical scale and reading the SWC. Subtract the SWC from AWC to obtain F_n

$$F_n \text{ (inches)} = AWC \text{ (inches)} - SWC \text{ (inches)}$$

f. If a rain occurs, then that amount of rain should be added to the soil water content. The SWC cannot be brought up to a point greater than the AWC. This is illustrated in the example in Paragraph 1.k.

g. An alternative procedure for determining when and how much to apply compares the percent soil water deficiency (SWD_p) with MAD for a given crop. The following procedure is used to determine SWD.

(1) Soil water content (SWC) measurements are taken at a time when it is the judgment of the irrigator that it is almost time to irrigate.

(2) The SWC is subtracted from AWC which gives soil water deficiency (SWD).

$$SWD \text{ (inches)} = AWC \text{ (inches)} - SWC \text{ (inches)}$$

(3) The SWD is divided by AWC and multiplied by 100 and gives soil water deficiency (SWD_p).

$$SWD_p = (SWD/AWC)100$$

where SWD_p is a percent

(4) Compare SWD_p with MAD. If SWD_p is significantly less than MAD, there is no need to irrigate at that time. When SWD_p is nearly the same or greater than MAD the crop should be irrigated.

(5) If the crop is ready for irrigation, then SWD equals the net amount of water that should be applied (F_n).

(6) An example of this procedure is given in Paragraph 1.1.

h. There are a number of methods for measuring or estimating soil water content. These methods are presented in Measuring Soil Water Content.

i. The procedure for determining the soil water content is covered under each method for measuring or estimating soil water content.

j. Determining when to apply an irrigation using plant moisture stress symptoms is not a desirable method. Generally, by the time plants indicate moisture stress, yields will be reduced or quality will be affected. CROPS, Critical Growth Periods section provides information on plant moisture stress symptoms.

k. The following example illustrates the procedure given in Paragraph 1.e. for predicting when and how much to apply using soil water content (SWC) measurements.

(1) Given

(a) AWC of soil at the site is 6 inches

(b)   MAD for the crop being grown is 50 percent

(2)   Find

(a)   Develop a graph which is used to predict when and how much to apply

(b)   Show how the graph is used

(3)   Solution

(a)   On the vertical scale, left hand side of the graph show SWC in inches, Figure 1.1

(b)   Locate the 6-inch AWC point

(c)   Determine SWC_{MAD}

$$SWC_{MAD} \quad = AWC \times (MAD/100)$$
$$= 6 \times (50/100)$$
$$= 3 \text{ inches}$$

(d)   Identify the SWC_{MAD} point on the graph

(e)   Field is irrigated April 15 and checked 2 days after irrigation and the soil is at field capacity (FC)

(f)   Date of irrigation is shown on graph

(g)   Field is checked on April 25 and SWC is 5.5 inches, Point 1 on graph.

(h)   Field is checked on May 8 and SWC is 4.0 inches, Point 2 on graph.

(i)   A line is drawn from Point 1 to Point 2 and projected to MAD line. This indicates the next irrigation will be needed on about May 17.

(j)   Field is checked 5 days before proposed irrigation and SWC is 3.5 inches. Point 3 on graph.

(k)   A line is drawn from Point 2 to Point 3 and projected to MAD line. This confirms the irrigation date of May 17.

(l)   If the irrigation had been based on the first check (a line drawn from the date of irrigation, April 15, to Point 1 and projected to the MAD line), the approximate irrigation date would have been June 14. The crop would have been stressed if the field was irrigated at that time. This shows the importance of making several checks between irrigations.

(m) The farmer plans to irrigate on May 17, the amount of water he needs to apply is 3 inches because this is the amount that will be depleted when MAD is 50 percent.

(n) Field is checked on May 25 and SWC is 5 inches, Point 4 on graph.

(o) Field is checked on June 1 and SWC is 4.25 inches, Point 5 on graph.

(p) A line is drawn from Point 4 to Point 5 and projected to MAD line. This indicates the next irrigation will be needed on about June 11.

(q) Field is checked 4 days before proposed irrigation and SWC is 2.5 inches, Point 6 on graph.

(r) A line is drawn from Point 5 to Point 6. This shows that the farmer should have irrigated on June 5. He has exceeded the 50 percent MAD level and the crop could be stressed some. The farmer needs to irrigate immediately.

(s) The farmer plans to irrigate immediately. He needs to apply the following amount.

$$F_n = AWC - SWC = 6.0 - 2.5 = 3.5 \text{ inches}$$

(t) The field is irrigated on June 8.

(u) Field is checked on June 15 and SWC is 4.5 inches, Point 7 on the graph.

(v) The next day it rains 2.5 inches. This is enough water to refill the root zone because only 1.5 inches is needed to bring the root zone back to field capacity.

$$\begin{aligned} F_n &= AWC - SWC \\ &= 6.0 - 4.5 \\ &= 1.5 \text{ inches} \end{aligned}$$

(4) Graph for scheduling irrigations, Figure 1.1.

1. The following example illustrates the procedures given in Paragraph 1.g.

(1) Given

(a) AWC of soil at the site is 6 inches

Figure 1.1
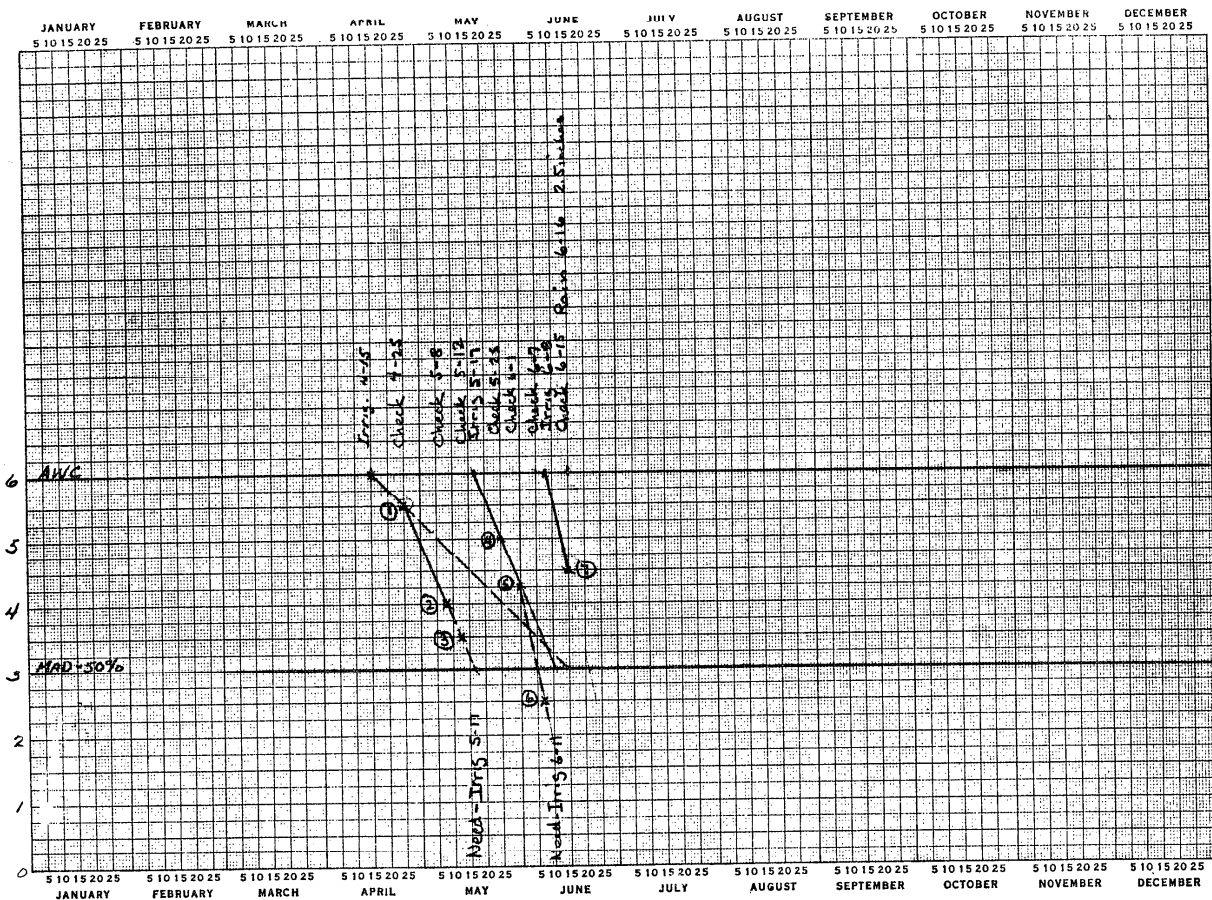
        (b)   MAD for crop being grown is 50 percent

    (2)   Find

        (a)   When should the crop be irrigated

        (b)   How much water should be applied

    (3)   Solution

        (a)   Farmer estimates that it is about time to irrigate

        (b)   Field is checked and SWC is 4.0 inches

        (c)   Determine SWD_p. First determine SWD.

$$SWD = AWC - SWC$$
$$= 6.0 - 4.0$$
$$= 2.0 \text{ inches}$$

$$SWD_p = (SWD/AWC)100$$
$$= (2.0/6.0)100$$
$$= 33.3 \text{ percent}$$

The 33.3 percent is considerably less than the 50 percent MAD value. The farmer can wait several more days before he needs to be concerned about irrigating.

        (d)   The field is checked 4 days later and the SWC is 3.5 inches.

        (e)   Determine SWD_p.

$$SWD = 6.0 - 3.5$$
$$= 2.5 \text{ inches}$$

$$SWD_p = (2.5/6.0)100$$
$$= 41.7 \text{ percent}$$

The 41.7 percent is still less than the 50 percent MAD value, but the irrigator should consider irrigating in about 3 or 4 days. In 4 days time the soil water content decreased 0.5 inches or about 0.1 inch per day (0.5 ÷ 4 = 0.125 inches). There is approximately 0.5 inches of moisture before 50 percent MAD is reached (6 x 50 ÷ 100 = 3.0 and 3.0 ÷ 2.5 = 0.5). This gives about 4 more days before MAD of 50 percent is reached. (0.5 ÷ 0.125 = 4 days).

.2.   Use of consumptive use mass curves.

    a.   The use of consumptive use mass curves or cumulative consumptive use curves is another method which gives an approximate date of irrigation.

The use of mass curves does not reflect the daily water use of alfalfa or irrigated pasture which are periodically cut or grazed in a rotational system.   These curves are given in WATER REQUIREMENTS, Consumptive Use Values, Paragraph .23.

If these curves have not been prepared, they can be developed in the following manner.

(1)   On the left hand side of the graph paper (rectangular grid-time series - 1 year by days x 250 divisions) divide grid into the appropriate inch values; starting with 0.   Figure 2.1.

(2)   Take the monthly gross consumptive use data for a crop and plot the cumulative totals on the graph.   Normally, each plot point will be at the mid point for each month, except where the gross monthly consumptive use is evaluated for a time period of less than 1 month.

Refer to WATER REQUIREMENTS, Paragraph .21 for monthly gross consumptive use.

(3)   Connect the points with a smooth line starting with 0 at the planting data and ending at the harvest date.

(4)   An example is given in Paragraph 2.e.

b.   To use the cumulative consumptive use graphs the following procedure should be used.   An example of this procedure is given in Paragraph 2.e.(3).(b).

(1)   At the start determine the soil water content (SWC) using one of the methods discussed in Measuring Soil Water Content section. Determine available water content (AWC).   Add this value to the cumulative amount which occurred on the day the measurement was taken.   Plot this value on the graph.

(2)   From the plotted point move horizontally to the right until the cumulative curve is intersected.   At this point move vertically downward until the horizontal scale is intersected and read the date. This gives the approximate date for the next irrigation.

(3)   At the next irrigation add the net irrigation to the point on the cumulative curve on the date of irrigation.   Project the point horizontally to the right until the cumulative curve is intersected, then move downward and read the approximate date of the next irrigation.

(4)   Repeat the process to meet the consumptive need of the crop.

(5)   The effective rainfall can be added to the curve in the same manner to find about how many days irrigation should be delayed.

c.   Irrigation dates and net depth of application will have to be adjusted for some crops because of harvesting or cultivating, i.e., alfalfa, strawberries, corn, sugar beets, etc.

d.   Soil water content measurements should be made periodically to correct for differences in consumptive use. The cumulative consumptive use curves represent a long term average water use. Consumptive use for a given year will vary from the average because the climatic factors will probably be different from the average values used in developing the consumptive use data.

e.   Example of preparing and using the cumulative consumptive use curves.

    (1)   Given

        (a)   Crop, grain corn

        (b)   Gross monthly consumptive use

Month	Inches	Month	Inches
May 5	1.79	Sept.	4.49
June	3.75	Oct.	2.28
July	6.76	Nov. 1	.02
Aug.	6.88		

        (c)   Normal net irrigation replacement is 4 inches

        (d)   A measurement was made on June 20 and the AWC was 2.5 inches.

    (2)   Find

        (a)   Prepare cumulative consumptive use graph

        (b)   Approximate date of irrigation

    (3)   Solution

        (a)   Preparation of graph

Month	Monthly cu inches	Cumulative cu inches	Plotting date
May 31	1.79	1.79	May 18
June 30	3.75 (+ 1.79 =)	5.54	June 15
July 31	6.76 (+ 5.54) =)	12.30	July 15
Aug. 31	6.88 (+ 12.30 =)	19.18	Aug. 15
Sept. 30	4.49 (+ 19.18 =)	23.67	Sept. 15
Oct. 31	2.28 (+ 23.67 =)	25.95	Oct. 15
Nov. 1	.02 (+ 25.95 =)	25.97	Nov. 1

Plot on graph cumulative consumptive use values for the plotting dates shown, Figure 2.1.

(b) Use of graph

On June 20 the cumulative consumptive use to date is about 6.5 inches. This value plus the available soil water of 2.5 inches equal 9.0 inches. Plot this point on the graph. Move to the right and intersect the cumulative curve, move vertically down and read July 1. Add 4 inches to the cumulative curve at the July 1 point and plot a new point. Move to the right and intersect the cumulative consumptive use curve, move vertically down and read July 17. Repeat this process. For this case, it is estimated that irrigations will be needed on about:

July 6
July 24
August 8
August 27

Another irrigation could be given on about September 20, but the crop is in a late maturing stage and another irrigation is not needed.

Figure 2.1

Corn, grain

Cumulative C.U. - inches

App. Depth (in.)
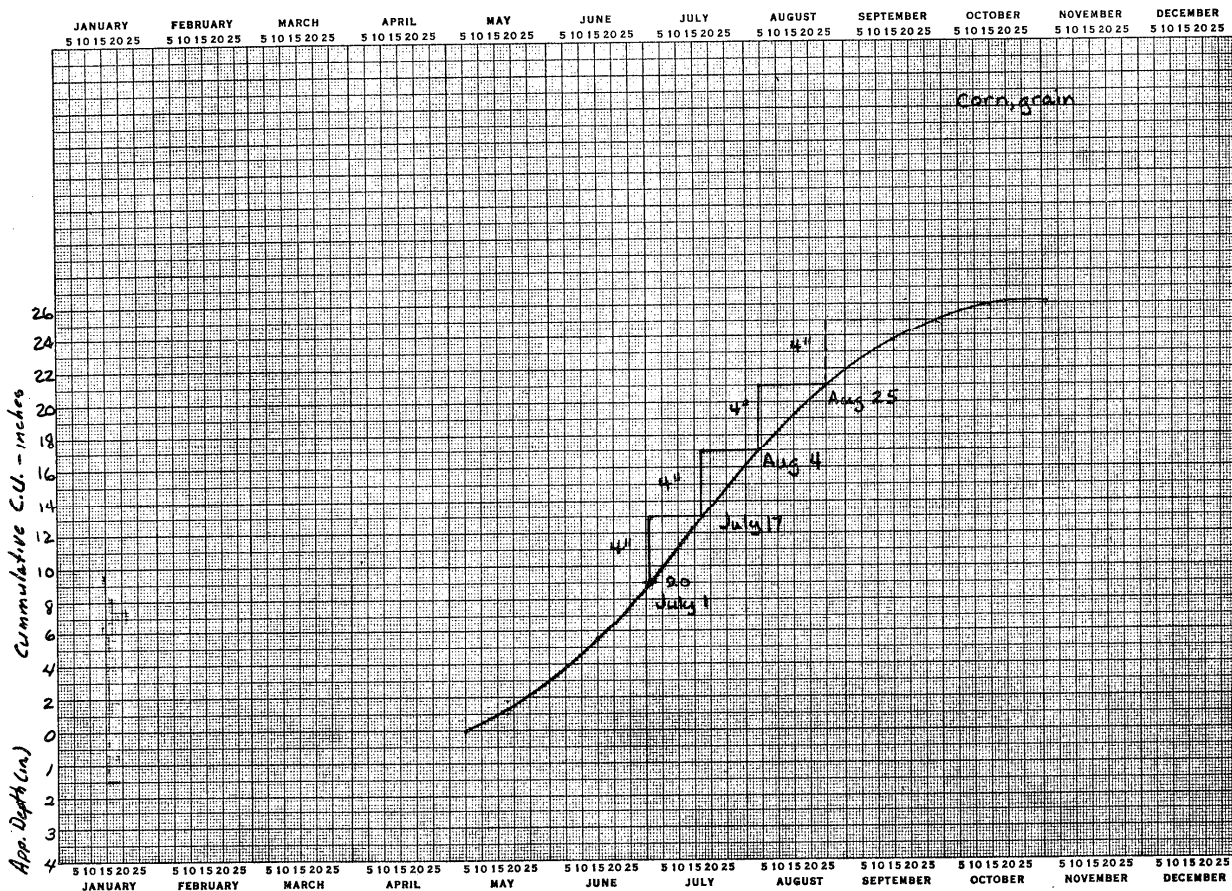
MEASURING SOIL WATER CONTENT

10. Feel and appearance method

a.   The feel and appearance method is one of the easiest methods to use for estimating soil water content. Although this method is not the most accurate, the irrigator, with experience and judgment, should be able to estimate the soil water content within a reasonable degree of accuracy.

b.   Descriptions of soil water content, Table 10.1 and Figure 10.1.a., b., and c. are useful aids in the determination of soil water content.

c.   A shovel, soil auger, or sampling tube is needed to obtain soil samples.

d.   The following procedure is used to estimate the soil water content.

(1)   Obtain a soil sample from a selected depth or strata.

(2)   Compare a handful of soil that has been squeezed very firmly with the photographs, Figure 10.1.a, b, or c or the written descriptions in Table 10.1.

(3)   Estimate and record the available soil water content as a percentage.

e.   A form similar to Figure 10.2 can be used to record and compute the estimated soil water content for the soil profile.

(1)   Record in column 1 the depth at which soil measurement was taken.

(2)   In column 2, record the soil texture.

(3)   Record in column 3 the available water capacity (AWC) for each increment of depth sampled.

(4)   In column 4, record the soil water content in percent.

(5)   In column 5, record the computed inches of soil water content (SWC) in each sampled layer of soil. These values are obtained by multiplying the AWC values in column 3 by the percentage values in column 4 divided by 100.

(6)   Compute, and record in column 6, the soil water deficiency (SWD) in each sampled layer of soil. The SWD is found by subtracting the SWC (column 5) from the AWC (column 3). The sum of the values in

Table 10.1 Guide for Judging how much Moisture is Available for Crops

Available soil moisture remaining	Feel or Appearance of Soil			
	Loamy Sand or Sand	Sandy Loam	Loam and Silt Loam	Clay Loam or Silty Clay Loam
0 percent Wilting point	Dry, loose, single grained, flows through fingers.	Dry. loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked, sometimes has loose crumbs on surface.
25 percent	Appears to be dry, will not form a ball with pressure. 1/	Appears to be dry, will not form a ball. 1/	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure. 1/
50 percent	Appears to be dry, will not form a ball with pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball. ribbons out between thumb and forefinger.
75 percent	Tends to stick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily is relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity (100 percent)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.

1/ Ball is formed by squeezing a handful of soil very firmly.

MODERATELY FINE TEXTURE
Clay Loams and Silty Clay Loams

-- 0 to 25% Available Moisture --
Crumbles readily, will hold
together but "balls" with diffi-
culty and breaks easily.

-- 25 to 50% Available Moisture --
Does not crumble, forms readily,
will "ball" with pressure.

-- 50 to 75% Available Moisture --
Forms "ball" readily, will "ribbon"
out between thumb and forefinger.
Somewhat slick feeling.

-- 75 to 100% Available Moisture --
Easily "ribbons" out. Has "slick"
feeling.

Photos Courtesy Okla. Ext. Service

Figure   10.1.a

MEDIUM TEXTURE
Loams and Silt Loams

-- 0 to 25% Available Moisture --
Crumbles easily, tends to hold
together from hand pressure.

-- 25 to 50% Available Moisture --
Somewhat crumbly, will hold together
in hand with pressure.

-- 50 to 75% Available Moisture --
Forms "ball" readily, will "slick"
slightly with pressure.

-- 75 to 100% Available Moisture --
Forms "ball" easily, fairly friable,
"slicks" readily.

Photos Courtesy Okla. Ext. Service

Figure 10.1.6

COARSE TEXTURE
Sandy Loams and Loamy Sands

-- 0 to 25% Available Moisture --
Dry, loose, flows through fingers.

-- 25 to 50% Available Moisture --
Looks dry, will not form ball with
pressure.

-- 50 to 75% Available Moisture --
Will form loose ball under pressure,
will not hold together even with
easy handling.

-- 75 to 100% Available Moisture --
Forms weak ball, breaks easily, will
not "slick".

Photos Courtesy Okla. Ext. Service
5, L—25307

Figure 10.1.c

column 6 is the total soil water deficiency in the crop root zone. This could represent the net application depth if the total SWD has reached the MAD level.

    f.   The amount of soil water which is available for plant use is reduced by salts in the soil. If there are any salts in the soil, the available water capacity (AWC) should be adjusted. The reduction factor is given in Figure 10.2. The following procedure is used to correct for soil salinity.

    (1)   Determine the electric conductivity (ECe x 10^3 25°C) for the salts in the soil.

    (2)   Enter the electrical conductivity value on the chart, Figure 10.2, and read the reduction factor (F).

    (3)   Calculate the adjusted AWC by multiplying AWC by F.

    (4)   The following is an example using this procedure.

    (a) Given

    <u>1</u> AWC = 5.8 inches
    <u>2</u> ECe = 8.0 mmhos

    (b) Adjusted AWC

$$AWC_{adj} = AWC \times F$$

$$= 5.8 \times 0.80$$

$$= 4.64 \text{ inches}$$

11.   Gravimetric method.

    a.   This procedure is the most accurate method for determining the soil water content.

    b.   The following equipment is required.

    (1)   Moisture proof seamless aluminum or tin sample boxes (can) with a capacity of 3 ounces or more to contain sample for drying.

    (2)   Beam balance with a minimum of 500-gram capacity, accurate to 0.1 gram.

    (3)   Drying oven, with thermometer, capable of maintaining a temperature of 220°F to 240°F. (105°C to 115°C).

    (4)   Core soil sampler to take bulk density samples. Figure 11.1. a. b. and c show a sampler which can be constructed to collect a rather large sample.

Format for figuring the net amount of water needed for an irrigation

(1)	(2)	(3)	(4)	(5)	(6)
Depth	Soil texture	Available water capacity	Soil water content before irrigation		Soil water deficiency
(feet)		(inches)	(percent)	(inches)	(inches)
0-1	Medium	2.0	35	0.7	1.3
1-2	Medium	2.0	50	1.0	1.0
2-3	Moderately coarse	1.2	50	0.6	0.6
3-4	Moderately coarse	1.2	75	0.9	0.3
Total		6.4	--	3.2	3.2

Figure 10.2

Drive cap for rubber mallet

Rod holes @ 6" spacing

Sample handle

Depth control, foot pressure rod & lift handle

½"⌀ steel rod

6"

Auger hole

6"

Center of sample chamber

60 cm³ sample chamber

Sample barrel

Undisturbed soil

NOT TO SCALE
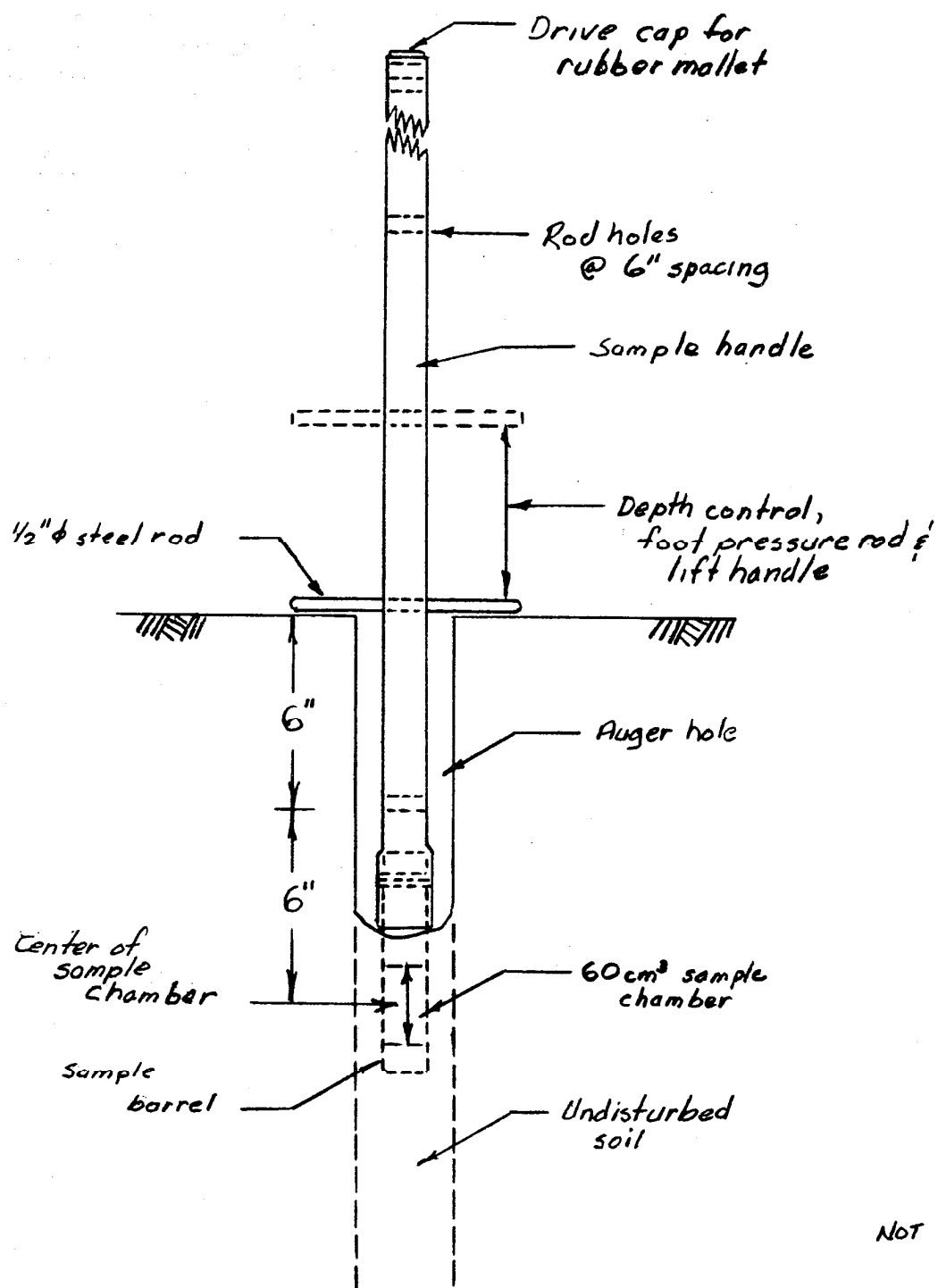
Figure   11.1.a. Madera Soil Sampler

Top view

Twist latch

Sample Chamber 60 cm³

1½"ϕ stainless steel

Spatula or putty knife slots

Sharpened outside edge

Scale: Approx 1" = 1"

Front view

Side view
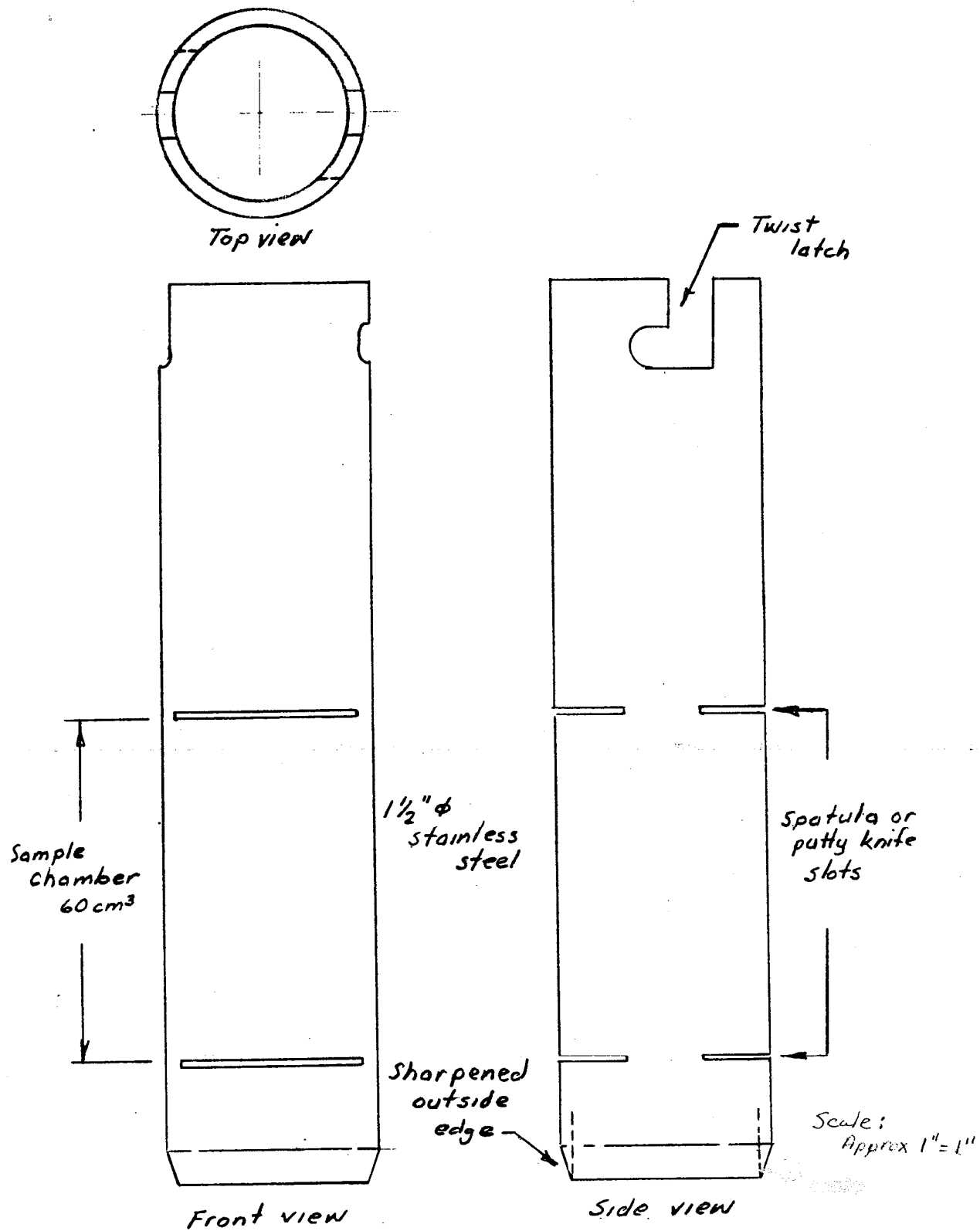
Figure 11.1.6 Madera Soil Sampler Barrel
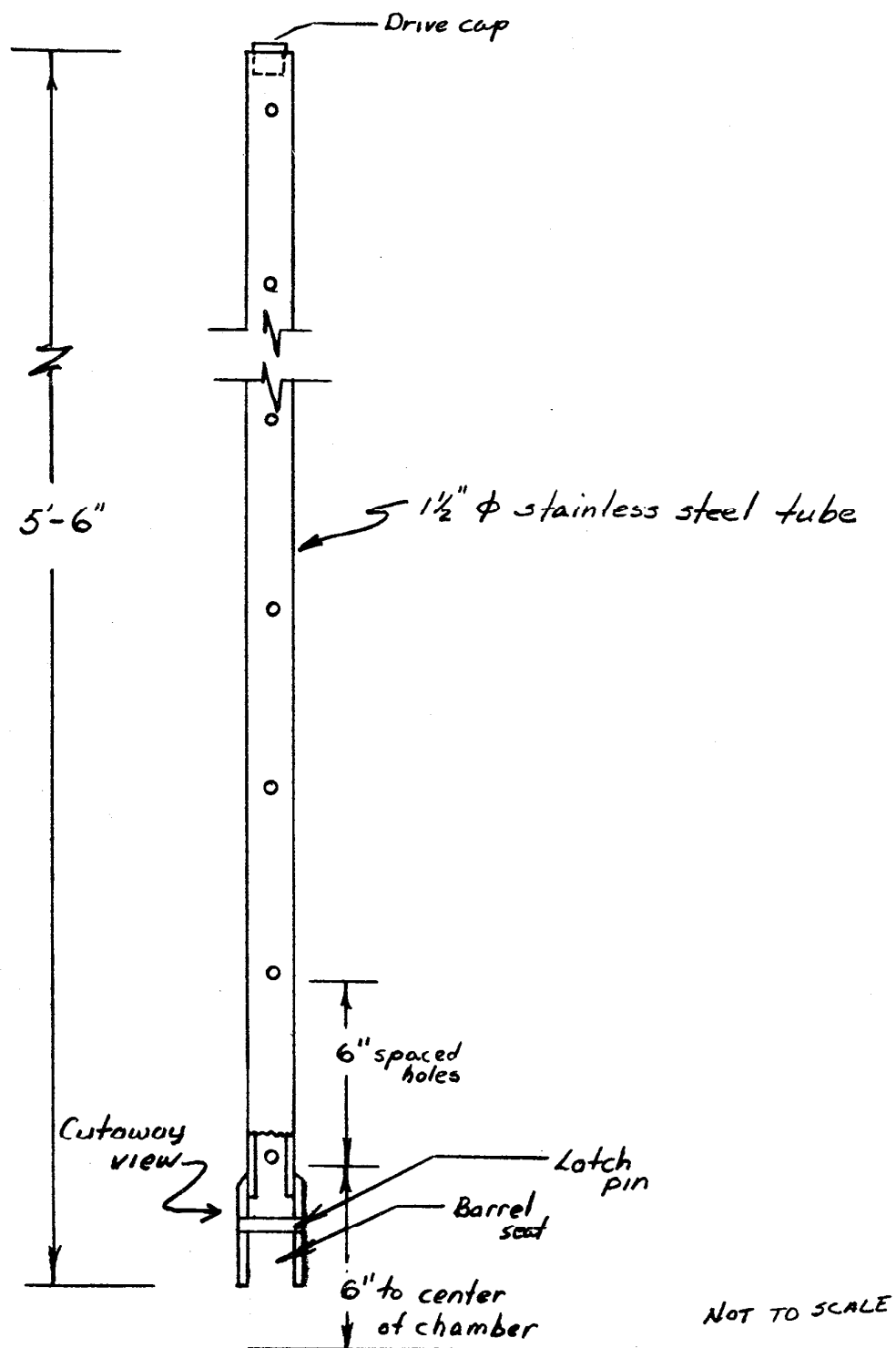
Figure   11.1.c. Madera Soil Sampler Handle

PHYSICAL PROPERTIES OF SOIL
FOR
IRRIGATION WATER MANAGEMENT

Work Sheet

Owner_____ State_____ County_____ Legal Description_____ Date_____

Sample No.	Horizon	Depth	Texture	Sample Depth	Sample Wet Weight	Sample Dry Weight	Water Loss	Tare	Net Dry Weight	Volume of Sample	Moisture Per-centage	Bulk Density	Total Water	Total Water for Evaluation	Soil Series
		in		in	g	g	g	g	g	cc	%	g/cc	in/in	in	
									Site No._____						
									Site No._____						
									Site No._____						

Dry weight (D_w) of soil = DW - TW = g   Weight of water lost (W_w) = WW - DW = g   Bulk density (Db_d) = $\frac{D_w(g)}{Vol. (cc)}$ = g/cc

Percent water content - dry weight (P_d) = $\frac{W_w}{D_w}$ x 100 = %   Soil water content (SWC) = $\frac{Db_d \times P_d \times d}{100 \times 1}$ = inches

Figure 11.2

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c.   The following procedure should be used in determining soil water content. The information can be recorded on a work sheet similar to Figure 11.2.

(1) Collect a representative soil sample, of known volume in cubic centimeters (cc) using the core sampler. Place the sample in the container and seal with lid. Weigh can with the wet soil in it and record the weight as: WW = weight of container plus soil and water.

(2) There are two methods for drying the soil samples. The preferred method is (a).

(a) Remove the lid and place it under the can and place open container in the oven at a temperature between 220°F to 240°F (105°C to 115°C). Leave the sample in the oven until it attains a constant weight. It is important that all moisture be removed from the sample. Drying time will take about 24 hours. Near the end of the 24-hour period, take the sample out of the oven, weigh it and then replace in the oven for an additional hour, and reweigh. If there has been no weight change during the second drying, the water content determination will be correct.

(b) An alternate to oven drying is a 250 watt infrared heat lamp. Empty the sample from the container onto a 1 square foot piece of aluminum foil and weigh the wet sample and then let the soil air dry. After it appears dry, pack the soil into a 6-inch square and place it 4 inches below the infrared heat lamp for 2 hours or 4 hours if air drying is eliminated. Check the weight and extend the drying time if the sample has not reached constant weight. The underlying surface has to be reasonably heat resistant. Use the same procedure for computing soil water content. Be sure to deduct the tare weight of the aluminum foil.

(3) Remove the can of oven-dried soil from the oven, cool the container with the lid on it, and weigh. Record this weight as: DW = weight of container with lid and dry soil.

(4) Empty the container, wipe clean, and weigh with the lid. Record the weight as: TW = tare weight of container.

(5) Compute the bulk density and the total soil water content (TSWC) by the following formulas:

Dry weight (D_w) of soil = DW - TW = grams(g)

Bulk density (Db_d) $= \dfrac{Dw(g)}{Vol.(cc)}$ = g/cc

Weight of water lost (W_w) = WW - DW = g

Percent water content - dry weight $(P_d) = \dfrac{W_w}{D_w} \times 100 = \%$

Total soil water content (TSWC) $= \dfrac{Db_d \times P_d \times d}{100 \times dw} = $ inches per inch

> where d = soil depth taken as 1 inch
> dw = density of water taken at 1

(6) The total soil water content (TSWC) includes moisture which is not readily or not available for plant use. At a point known as the permanent wilting point (P_w) the plant can no longer obtain enough soil water to meet transpiration requirements. The permanent wilting point has been established at 15-atmospheres of tension and is normally determined in the laboratory using a pressure-membrane apparatus. Where laboratory data is not available, one of the following procedures can be used to estimate the wilting point.

(a) This procedure requires knowledge of the percent clay, less any clay size carbonate particles, of the soil being measured. For many soils this procedure will provide a close estimate of the wilting point. The wilting point is calculated with use of the following equation:

$P_w = 0.4 \times$ clay (%)

where

> P_w is the wilting point, using the clay content, expressed as percent of water on a dry weight basis.

(b) This procedure can be used where only the soil texture is known. The values given represent an average wilting point for the given texture.

Texture	P_w
Clay	25
Silty clay	19
Sandy clay	17
Silty clay loam	13
Clay loam	13
Sandy clay loam	11
Silt loam	5.5
Loam	7
Very fine sandy loam	4
Fine sandy loam	4
Sandy loam	4
Loamy fine sand	3

```
Loamy sand                    3
Fine sand
Sand                          2
```

P_w is expressed as percent water on a dry weight basis. The values given do not apply to soils having soil fragments larger than 2.0 millimeters.

(7) To determine the soil water content (SWC), P_w percentage is first converted to inches of water (WP). WP is then subtracted from TSWC to obtain SWC.

$$WP = \frac{Db_d \times Pw \times d}{100 \times dw} = \text{inches/inch of depth}$$

where
  d = soil depth taken as 1 inch
  Db_d = the same value as the soil being evaluated.

  SWC = TSWC - WP = inches/inch of depth

(8) To determine the SWC for a given increment of depth multiply SWC by the depth, in inches, being evaluated. The following alternative method can be used to determine the SWC.

$$SWC = \frac{Db_d \times (P_a - P_w) \times d}{100 \times 1_w}$$

where
  d = the increment of soil depth being evaluated, inches.

d. To determine the available water capacity (AWC) it is necessary to make tests on soils at field capacity (FC). These measurements are made after an irrigation or effective rainfall. Before making the measurements allow about 24 hours for sand and about 48 hours for clay, for the gravitational water to drain. Determine AWC using the above procedure, where SWC becomes AWC.

e. The following is an example using this method for measuring soil water.

(1) Given

(a) Three samples are taken 48 hours after irrigation for the determination of AWC.

Owner_____ State_____ County_____ Legal Description_____ Date_____

Sample No.	Horizon	Depth	Texture	Sample Depth	Sample			Tare	Net Dry Weight	Volume of Sample	Moisture Per-centage	Bulk Density	Total Water	Total Water for Evaluation	Soil Series
					Wet Weight	Dry Weight	Water Loss								
		in		in	g	g	g	g	g	cc	%	g/cc	in/in	in	
								Site No. 1							
1		0-12	vfsl	6	72.84	70.46	2.38	23.73	46.73	32.23	5.09	1.45	.074	0.89	Jalup vfsl
2		12-36	vfsl	18	76.72	73.36	3.36	24.05	49.31	32.23	6.81	1.53	.104	2.50	
3		36-60	sl	48	79.02	74.38	4.64	23.46	50.92	32.23	9.11	1.58	.144	3.46	
								Site No._____							
								Site No._____							

Dry weight (D_w) of soil = DW - TW = g   Weight of water lost (W_w) = WW - DW = g   Bulk density (Db_d) = $\dfrac{D_w(g)}{Vol.\ (cc)}$ = g/cc

Percent water content - dry weight (P_d) = $\dfrac{W_w}{D_w}$ x 100 = %   Soil water content (SWC) = $\dfrac{Db_d \ x \ P_d \ x \ d}{100 \ x \ 1}$ = inches

Figure 11.3

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(b) Basic data collected (other data is shown on worksheet
Figure 11.3.

Sample No.	1	2	3
Texture	vfsl	vfsl	sl
WW g	77.16	78.90	80.08
DW g	78.0	73.36	74.38
TW g	23.73	24.05	23.46
Vol. cc	32.23	32.23	32.23
% clay	10	7	9

(2) Find the soil water content (SWC) of the soil samples

(3) Solution (solution will be shown for only sample No. 1)

(a) Water loss

$$W_w = WW - DW$$
$$= 77.16 - 70.46$$
$$= 6.70g$$

(b) Dry weight

$$D_w = DW - TW$$
$$= 70.46 - 23.73$$
$$= 46.73g$$

(c) Bulk density

$$Db_d = \frac{D_w}{Vol.}$$

$$= \frac{46.74}{32.23}$$

$$= 1.45$$

(d) Percent water content

$$P_d = \frac{W_w}{D_w} \times 100$$

$$= \frac{6.70}{46.73} \times 100$$

= 14.34%

(e) Total soil water content

$$TSWC = \frac{Db \times P_d \times d}{d100 \times dw}$$

$$= \frac{1.45 \times 14.34 \times 1}{100 \times 1}$$

= 0.208 inches/inch of depth

for 12" soil depth
  TSWC = .208 x 12
        = 2.5 inches

(f) Wilting point percentage

$$P_w = 0.4 \times clay \ (pct.)$$
$$= 0.4 \times 10$$
$$= 4.0\%$$

(g) Wilting point, inches

$$WP = \frac{Db_d \times P \times d}{100 \times 1}$$

$$= \frac{1.45 \times 4.00 \times 1}{100 \times 1}$$

= 0.058 inches/inch of depth

for 12" soil depth
  WP = .058 x 12
     = 0.70 inches

(h) Soil water content which is equal to AWC for 12"
soil depth

  AWC = SWC = TSWC - WP
            = 2.50 - 0.70
            = 1.80 inches

12. Neutron probe.

    a. The neutron probe provides a fast, accurate measurement of the
soil water content. The probe is used to monitor the soil water status
at the same location, at any depth and frequency desired.

b.   The neutron probe can be used for the following purposes.

(1)   to determine when to irrigate

(2)   how much to apply

(3)   moisture extraction by depth for various crops

(4)   distribution of moisture throughout the field

(5)   to estimate consumptive use

(6)   to determine depth of penetration or rate of movement of water in the soil.

c.   To use the neutron probe, it must be calibrated so that readings or count rate is related to actual soil water content. Soils have different chemical properties that affect the neutron readings and, therefore, calibration curves must be developed for each soil series. To calibrate the probe, gravimetric measurements must be made and related to the neutron count.

d.   At each site, permanent access tubes must be installed.

e.   The Federal Nuclear Regulatory Commission (NRC) regulations require a radioactive materials license for the possession and use of reactor produced isotopes. Most agencies require formal training of the users by an approved training agency. Regulations require that nuclear devices be kept in a secure, locked storage area.

f.   Further information on use of the neutron probe will be issued at a later date.

13.   Calcium carbide gas pressure method (Speedy moisture tester)

a.   This procedure involves the use of the Carbide Gas Moisture Tester and Eley Volumeter and measures the total soil water content. This method is accurate providing the soil sample is taken properly with the volumeter. There is a possibility of compacting the sample when pushing it into the soil.

b.   Soil water is expressed as a percentage of the dry weight of the soil which is determined by gas pressure. The amount of gas formed is dependent upon the amount of free water in contact with the calcium carbide reagent. A conversion chart relates gas pressure values to percent moisture on a dry weight basis.

c.   Equipment required

   (1)   Carbide type moisture tester - 26 gram size

   (2)   Twenty-six gram scale for weighing the sample

   (3)   Eley Volumeter, to determine the volume of soil to be tested

   (4)   Two steel balls weighing approximately 0.4 pounds each

   (5)   Calcium carbide reagent

   (6)   Calibration curve to convert wet moisture pressure gage reading to dry weight percentage, Figure 13.1.

   (7)   Knife

   (8)   Bucket type soil auger or shovel

   (9)   T-handle extension with adapter for the Eley Volumeter

   (10)   Forms to record data. Figure 13.2 shows a form which can be used.

d.   The following procedure should be used in collecting the soil water content data.

   (1)   Select a site and set up equipment. Auger a hole and take samples at desired depths and test the samples. Record depths at which samples were taken.

   (2)   Place three measures of reagent and the steel balls in the large chamber of the tester. Do not allow steel balls to strike gage area.

   (3)   Trim the soil at the end of the Volumeter. Set the indicator at 0 or near plus zero and record reading. Carefully weigh out 26 grams, carefully trimming the soil sample into the weight pan. Record the reading after the 26 grams of soil has been placed in the pan.

   (4)   Place the soil sample in the cup of the tester, then with the pressure vessel in a horizontal position, insert the cup in the vessel and tighten the clamp to seal the cup to the unit.

   (5)   Raise the vessel to a near vertical position so the soil in the cup falls into the large chamber with the reagent.

Gage Read. 1/	Oven Dry Moisture - Percent									
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
2	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
3	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
4	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9
5	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.9	6.0	6.1
6	6.2	6.3	6.4	6.5	6.6	6.8	6.9	7.0	7.1	7.2
7	7.3	7.4	7.5	7.6	7.7	7.9	8.0	8.1	8.2	8.3
8	8.4	8.5	8.6	8.7	8.8	9.0	9.1	9.2	9.3	9.4
9	9.5	9.6	9.7	9.8	9.9	10.1	10.2	10.3	10.4	10.5
10	10.6	10.7	10.8	11.0	11.1	11.2	11.3	11.4	11.6	11.7
11	11.8	11.9	12.0	12.2	12.3	12.4	12.5	12.6	12.8	12.9
12	13.0	13.1	13.3	13.4	13.5	13.7	13.8	13.9	14.0	14.2
13	14.3	14.4	14.6	14.7	14.8	15.0	15.1	15.2	15.3	15.5
14	15.6	15.7	15.9	16.0	16.2	16.3	16.4	16.6	16.7	16.9
15	17.0	17.1	17.3	17.4	17.5	17.7	17.8	17.9	18.0	18.2
16	18.3	18.4	18.6	18.7	18.9	19.0	19.1	19.3	19.4	19.6
17	19.7	19.8	20.0	20.1	20.3	20.4	20.5	20.7	20.8	21.0
18	21.1	21.3	21.4	21.6	21.7	21.9	22.0	22.2	22.3	22.5
19	22.6	22.8	22.9	23.1	23.2	23.4	23.5	23.7	23.8	24.0
20	24.1	24.3	24.4	24.6	24.7	24.9	25.0	25.2	25.3	25.5
21	25.6	25.8	25.9	26.1	26.2	26.4	26.5	26.7	26.8	27.0
22	27.1	27.3	27.4	27.6	27.7	27.9	28.0	28.2	28.3	28.5
23	28.6	28.8	28.9	29.1	29.2	29.4	29.6	29.7	29.9	30.0
24	30.2	30.4	30.5	30.7	30.8	31.0	31.1	31.3	31.4	31.6
25	31.7	31.9	32.0	32.2	32.3	32.5	32.7	32.8	33.0	33.1
26	33.3	33.5	33.6	33.8	33.9	34.1	34.3	34.4	34.6	34.7
27	34.9	35.1	35.2	35.4	35.5	35.7	35.9	36.0	36.2	36.3
28	36.5	36.7	36.8	37.0	37.1	37.3	37.5	37.6	37.8	37.9
29	38.1	38.3	38.4	38.6	38.8	39.0	39.1	39.3	39.5	39.6
30	39.8	40.0	40.1	40.3	40.5	40.7	40.8	41.0	41.2	41.3
31	41.5	41.7	41.8	42.0	42.2	42.4	42.5	42.7	42.9	43.0
32	43.2	43.4	43.5	43.7	43.8	44.0	44.2	44.3	44.5	44.6
33	44.8	45.0	45.1	45.3	45.5	45.7	45.8	46.0	46.2	46.3

1/ Carbide Moisture Tester - 3-minute readings

Figure 13.1. Carbide moisture tester conversion chart

DETERMINATION OF SOIL MOISTURE AND BULK DENSITY (DRY)
USING
ELEY VOLUMETER AND SPEEDY MOISTURE TESTER

Farm_____ Location_____ SWCD_____

Crop_____ Soil Type_____ Date_____ Tested by_____

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Thick-ness of Layer	Volumeter			% Wet Wt.	% Dry Wt.	% Wilting Point	% Soil Water	Bulk Density (g/cc)	Soil Water Content (in)	Soil Water Content at Field Capacity	Soil Water Deficit (in)
Texture		Reading Before (cc)	Reading After (cc)	Volume (cc)								
	d			V	W_p	P_d	P_w	SWC_p	Db_d	SWC	AWC	SWD
Wet weight of all samples 26 grams unless otherwise shown.									Totals			

$$Db_d = \frac{26}{V(1 + \frac{P_d}{100})}$$

$$SWC = \frac{Db_d \times SWC_p \times d}{100 \times 1}$$

$$SWC_p = P_d - P_w$$

See Instructions on Reverse Side

Fill out headings completely. Fill in lines in columns as tests are made. Be neat, accurate, and make a complete record.

Column 1   Record depth from ground surface to top and bottom of soil strata or portion of profile sampled. (12-24.)

Column 2   Thickness of layer. Difference of two values shown in Column 1. (24-12 = 12.)

Column 3   Reading of volumeter scale before sample is extruded.

Column 4   Reading of volumeter scale after sample is extruded.

Column 5   Difference between columns 3 and 4; (column 4 - column 3.)

Column 6   Reading of dial on Speedy Moisture Tester at completion of test. Percent moisture wet weight.

Column 7   Dry weight moisture percent from table in Speedy Moisture Tester.

Column 8   Known or estimated wilting point percentage for soil being tested.

Column 9   Available moisture percentage; (column 7 - column 8.)

Column 10   Bulk Density. Compute from equation No. (1).

Column 11   Depth of Available Moisture in soil at time of testing. Use equation No. (2).

Column 12   Depth of Moisture in Soil at Field Capacity using percent moisture Pd shown in top of column minus - column 8, then equation (2).

Column 13   Moisture deficiency; (column 12 - column 11.)

(6) Holding the moisture tester horizontally, manually rotate the device for 10 seconds so that the steel balls are put into orbit around the inside circumference, and then rest for 20 seconds. Repeat the shake-rest cycle for a total of 3 minutes. Do not allow the steel balls to fall against either the cap or the orifice leading to the dial, since this might cause damage.

(7) With the instrument in a horizontal position, read and record the gage pressure. Read the pressure gage to the nearest 0.1 percent and record.

(8) Release the pressure slowly, empty the contents, and clean the cap and the large chamber for the next test. When the sample is dumped, examine for lumps. If the soil sample was not completely broken down, increase the shake-rest cycles by one minute on the next test.

e. Precautions in the use of the Carbide Type Moisture Tester.

(1) Tests should not be made of saturated high organic soils.

(2) Make a preliminary test of any mineral soil with an unknown maximum water holding capacity using a 13-gram, rather than a 26-gram, sample to reduce the possible pressure generated in the vessel.

(3) In making any test, observe the pressure rise immediately after raising the pressure vessel to a vertical position. The initial pressure increase will be rapid; and after a few seconds, it will be steady until the tester is rotated. If the initial gage reading approaches 20 percent moisture, (a gage reading of about 17), release the pressure immediately by loosening the clamp enough to allow the gas to escape, then start over using a 13-gram sample.

f. To compute the SWC the following procedure can be used.

(1) Compute the volume of soil by subtracting the after reading from before reading of Eley Volumeter.

(2) Convert the gage reading, percent wet weight (W_p) to percent water content (P_d), dry weight, using the conversion chart, Figure 13.1.

(3) Determine the wilting point percentage (P_w). The procedure in Paragraph 11.c.(6) can be used to estimate P_w.

(4) Compute the soil water content percentage (SWC_p) by subtracting P_w from P_d.

$$SWC_p = P_d - P_w$$

Figure 13.3

UNITED STATES DEPARTMENT OF AGRICULTURE
Soil Conservation Service

DETERMINATION OF SOIL MOISTURE AND BULK DENSITY (DRY)
USING
ELEY VOLUMETER AND SPEEDY MOISTURE TESTER

Farm_____ Location_____ SWCD_____

Crop_____ Soil Type_____ Date_____ Tested by_____

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Thick-ness of Layer	Volumeter			$\tilde{\%}$ Wet Wt.	$\%$ Dry Wt.	$\%$ Wilting Point	$\%$ Soil Water	Bulk Density (g/cc)	Soil Water Content (in)	Soil Water Content at Field Capacity	Soil Water Deficit (in)
Texture		Reading Before (cc)	Reading After (cc)	Volume (cc)								
	d			V	W_p	P_d	P_w	SWC_p	Db_d	SWC	AWC	SWD
vfsl	12	0	16.44	16.44	8.6	9.1	4	5.1	1.45	89	1.80	0.91
vfsl	24	3.65	18.98	15.33	10.2	10.8	4	6.8	1.53	2.50	3.10	0.60
sl	24	2.00	16.55	14.55	12.1	13.1	4	9.1	1.58	3.45	2.90	0.55
Wet weight of all samples 26 grams unless otherwise shown.									Totals		7.80	2.06

$$Db_d = \frac{26}{V(1 + \frac{P_d}{100})}$$

$$SWC = \frac{Db_d \times SWC_p \times d}{100 \times 1}$$

$$SWC_p = P_d - P_w$$

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(5) Calculate the bulk density using the following equation.

$$Db = \frac{26 Pd)}{V(1+\frac{}{100})} = cc/g$$

(6) Compute the soil water content using the following equation.

$$SWC = \frac{Bb \quad s \; SWC \times d}{d \; 100 \; xpdw} = \text{inches for depth being evaluated}$$

where
   d = soil depth being evaluated, inches
   dw = density of water taken as 1

   g.   Evaluate the need for an irrigation according to Irrigation Timing section.

   h.   The available water capacity can be evaluated using this method of soil water measurement. The measurement is taken after irrigation. Before making the measurement allow 24 hours for sand, and 48 hours for clay, for the gravitational water to drain out of the soil profile.

   i.   The following is an example using this method for measuring soil water.

      (1) Given

         Three samples are taken for the determination of the soil water content. Samples are taken at the midpoints for the given depths with the information recorded on the form. Refer to Figure 13.3 for an example of a completed form using the given data.

Depth	Texture	Volumeter Reading Before cc	After cc	Gage Reading (%)	AWC (inches)
0-12	vfsl	0	16.44	8.6	1.80
12-36	vfsl	3.65	18.98	10.2	3.10
36-60	sl	2.00	16.55	12.1	2.90

MAD for the crop is 40 percent

      (2) Find

         (a) The soil water content of the soil samples

         (b) Is an irrigation needed and if so, how much?

      (3) Solution (only the solution for one sample will be shown)

(a) Volume of soil sample

$$V = (\text{Reading after}) - (\text{Reading before})$$
$$= 16.44 - 0 = 16.44 \text{ cc}$$

(b) Conversion of pressure reading, percent wet weight to percent dry weight. Read from conversion chart for $W_p = 8.6$, $P_d = 9.1\%$.

(c) Wilting point percentage. No laboratory clay content data is available, thus using the texture and referring to Paragraph 11.c.(6)(b) for a vfsl, use 4 percent.

(d) Soil water content percentage

$$SWC_p = P_d - P_w$$
$$= 9.1 - 4.0$$
$$= 5.1 \text{ percent}$$

(e) Bulk density

$$Db_d = \frac{26}{V(1 + \frac{P_d}{100})}$$

$$= \frac{26}{16.44(1 + \frac{9.1}{100})}$$

$$= 1.45 \text{ g/cc}$$

(f) Soil water content

$$SWC = \frac{Db_d \times SWC_p \times d}{100 \times 1}$$

$$= \frac{1.45 \times 5.1 \times 12}{100 \times 1}$$

$$= 0.89 \text{ inches}$$

(g) Soil water deficiency

$$SWD = AWC - SWC$$
$$= 1.80 - 0.89$$
$$= 0.91 \text{ inches}$$

(h)   The soil water deficiency in the root zone in this example is 1.51 inches (refer to Figure 13.3) and the available water capacity for the root zone is 7.80 inches. The soil water deficit percentage is SWD_p = (SWD ÷ AWC)100

$$= (1.51 ÷ 7.80)100$$
$$= 19.4\%$$

(i)   Is an irrigation needed?

An irrigation is not needed because SWD_p is less than MAD.

(j)   How much is needed?

If an irrigation were to be made, the amount needed would be 1.51 inches.

14.   Tensiometers

a.   Tensiometers are used to measure soil water suction. A tensiometer consists of a sealed water-filled tube equipped with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. The face of a typical tensiometer gauge is shown in Figure 14.1. Tension readings should be correlated with the soil water content for a specific soil. Tensiometers can be used to schedule irrigations and to determine the amount of water to apply. The main disadvantage of the tensiometer is that it is limited in operation to less than 100 centibars of suction. Normally, tensiometers operate from 0 to 80 centibars. This makes them best suited for medium and coarse textured soils. Tensiometers should not be ruled out for measuring the soil water content in clay soils because farmers sometimes irrigate before 50 percent depletion.

b.   The suction generated when the crop roots remove water from the soil draws water from the tensiometer tube through the porous tip and causes the gauge to register a vacuum. The drier the soil the higher the reading.

c.   When rainfall or irrigation renews the soil water supply, water will enter the tensiometer tube causing the gauge reading to lower.

d.   Tensiometers are set at a station setting up a zone of soil water control in the soil. A "station" consists of two or more tensiometers of different lengths placed near one another.

e.   Two stations may be enough in a field with uniform soil and slope. One station should be near the upper end of the field and the other near the lower end. More tensiometers may be needed in areas where the soils or slopes vary from representative soils or slopes in the field. When placing tensiometers the following suggestions should be kept in mind.
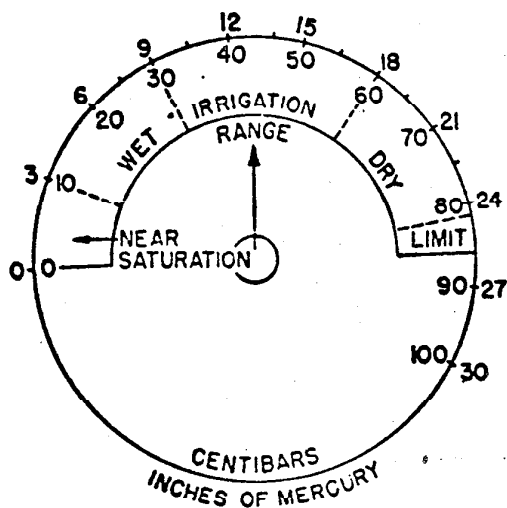
Figure   14.1   Tensiometer Dial

Table   14.1 RECOMMENDED DEPTH FOR SETTING TENSIOMETERS

Irrigation Depth of Active Root Zone	Shallow Tensiometer	Deep Tensiometer
Inches	Inches	Inches
18	8	12
24	12	18
36	12	24
48 or more (deep)	18	36

(1) In row crops, the tensiometers should be placed in the crop row. The shallow tensiometer tip should be under the edge of the furrow and the deep tensiometer tip under the center of the furrow.

(2) For orchards, the tensiometers should be located within the drip line and 3 to 6 feet from the tree trunk and on the sunny side.

(3) Measuring stations should be in representative soil areas of the field. Tensiometers should not be placed in low spots in the field.

(4) Stations should be at points where the plant population is representative of the field.

(5) The soil around the tensiometer station should not be compacted. The station should be approached from a row other than the one in which tensiometers are located.

(6) Tensiometers should be placed after the last freeze in the spring and should be removed before the first freeze in the fall. As an alternative where ground frost is minimal, the tensiometers can be buried under a deep cover of soil or manure.

f.   Depth of tensiometer installation is determined by the active root zone of the crop. This active root zone depends upon the crop, stage of growth, and depth of soil. For example, for a crop such as alfalfa, on a deep soil, tensiometers installed at a depth of 18 inches and 36 inches are recommended for each station. Recommended depths for setting tensiometers are given in Table 14.1. Tensiometers should not be installed in a fine textured soil at the shallow root depth because soil suction will exceed 100 centibars before the management allowed deficiency is reached.

g.   The tensiometer may be installed in an auger hole several times larger than the diameter of the tensiometer. The cup should be pushed into the soil at the bottom of the hole, if it is soft enough. If the soil is too hard, it may be softened by water or a small hole can be made to receive the cup. The hole should be refilled in layers and compacted around the tensiometer tube. A special tool supplied by the manufacturer may be used to install the tensiometer. It is important to get good soil contact.

h.   The above-ground parts of the tensiometer should be shielded from the sun to avoid a "thermometer" effect.

i.   Readings should be examined carefully to detect the effect of a leak. A leaky tensiometer can give misleading results. The tensiometer should be kept filled with deaired (boiled) water or serviced regularly with deairing equipment.

j.   Tensiometers readings should be correlated with the total soil water content in the soil profile at each station. This can be done by

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Figure   14.2

AVAILABLE WATER DEPLETION , percent
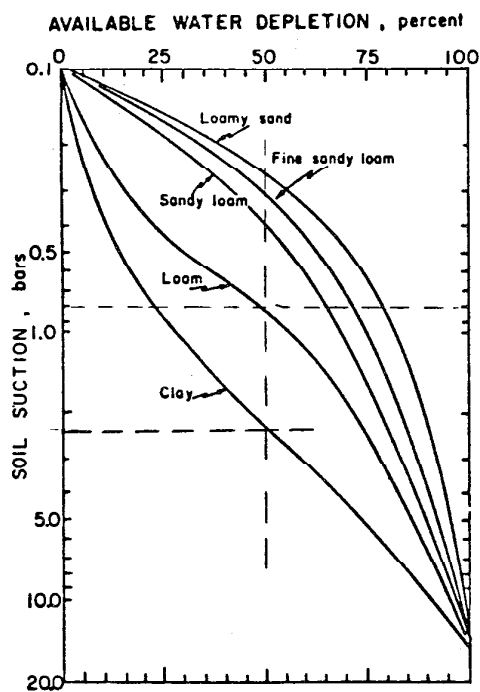
Water retention curves for
several soils plotted in terms of per-
cent available water removed, re-
drawn with change in scale from
Richards and Marsh (1961) and
Taylor (1965).

using the gravimetric method in Paragraph 11. Gravimetric measurements
should be made for several different tensiometer readings and plotted on
a graph. Figure 14.3.(a) shows an example of tensiometer readings
versus soil water content in the root zone.

k. To schedule irrigation it is necessary to know which tensiometers
should be used at a given site. The greatest soil suction will occur
near the soil surface where the roots are most active. This may cause
the activity of the soil water to decrease so rapidly that the range of
operation of the tensiometer will be exceeded. This will cause air to
enter the instrument.

(1) In sandy soils, tensiometers in the active root zone
should be used to schedule irrigation.

(2) For clayey soils, the soil suction will usually exceed
the operating range of the instrument before it is necessary to irrigate.
The graph in Figure 14.2 shows that it takes about 2.0 bars (200 centibars)
of suction to reach a 50 percent water depletion level for a clay. At
0.8 bar or 80 centibars the water depletion level would be about 25
percent. This makes it necessary to use the lower tensiometers in the
root zone to schedule irrigation.

(3) Soil suction values that indicate need for irrigation
will differ for the different soils. A guide for interpreting tensiometer
readings is given in Table 14.2.

l. To determine when and how much water to apply requires the
development of a relationship between soil suction and soil water content
for the root zone. An example of the development of this relationship
and use is given in Paragraph 14.m. The following procedure should be
used to collect data for the development of the soil suction-soil water
content relationship.

(1) Select a tensiometer which will not lose its suction.
Generally, the tensiometer in the second or third quarter should be
used.

(2) Measure the soil water content in the root zone. Record
the tensiometer readings at time of soil water content measurement.

(3) Make a number of measurements at different tensiometer
readings.

(4) Plot the data on graph paper.

m. Example of developing a graph for estimating when and how much
water to apply.

Table **14.2**   INTERPRETATION OF TENSIOMETER READINGS

* Dial Reading		Interpretation
Inches of Mercury	Centi-bars	
Nearly Saturated	0	Near saturated soil often occurs for a day or two following irrigation. Danger of water-logged soils, a high water table, poor soil aeration, or the tensiometer may have broken tension, if readings persist.
3	10	
Field Capacity	11	Field capacity. Irrigations discontinued in this range to prevent waste by deep percolation and leaching of nutrients below the root zone. Sandy soils will be at field capacity in the lower range, with clayey soil at field capacity in the upper range.
6	20	
9	30	
Irrigation Range		Usual range for starting irrigations. Soil aeration is assured in this range. In general, irrigations start at readings of 30-40 in sandy textured soils (loamy sands and sandy loams). Irrigations usually start from 40-50 on loamy soils, (very fine sandy loams and silt loams). On clay soils (silty clay loams, silty clays, etc.) irrigations usually start from 50-60. Starting irrigations in this range insures maintaining readily available soil moisture at all times.
12	40	
15	50	
18	60	
Dry		This is the stress range. However, crop not necessarily damaged or yield reduced. Some soil moisture is readily available to the plant but is getting dangerously low for maximum production.
21	70	
24	80	Top range of accuracy of tensiometer, readings above this are possible but the tensiometer will break tension between 80 to 85 centibars.

* Indicative of soil conditions where the tensiometer is located. Judgment should be used to correlate these readings to general crop conditions in the field.

(1) Given

    (a) Tensiometers which are located in the second and third quarter of a 4-foot root zone.

    (b) Tensiometer for the third quarter is selected for tension readings.

    (c) The following data was collected.

Soil Texture	Depth (inches)	AWC (in/ft)
loam	0-24	2.0
vfsl	24-48	0.95

Total AWC = 5.90 inches

Tensiometer reading (centibars)	SWC for 4-foot profile (inches)	SWD* for 4-foot profile (inches)
60	2.36	3.54
55	2.94	2.96
50	3.54	2.36
45	4.12	1.78
40	4.72	1.18

*SWD = AWC - SWC

    (d) The following additional data was collected to show why the tensiometer in the third quarter was selected. The soil water content is for the quarter of the root zone in which the tensiometer is located.

Soil Suction (centibars)	Second Quarter loam SWC (in/ft)	Third Quarter vfsl SWC (in/ft)
33	1.97	0.95
100	1.21	0.43
1500	0	0
MAD@50%	.82	0.65

    (2) Find

(a) Develop a graph to estimate the soil water content (SWC) and soil water deficiency (SWD) for a 4-foot profile.

(b) Show how to use the graph to estimate when and how much to apply.

(c) Show why the third quarter of the root zone was selected for determining when and how much to apply.

(3) Solution

(a) On graph paper (preferable--semi-logarithmic) plot SWC versus tensiometer readings and connect the points. If necessary, extend the line to cover a range from field capacity to the MAD level set for the crop being irrigated. Indicate the MAD point on the graph. Figure 14.3.(a) was developed for the data given (refer to SWC-curve).

(b) To use the SWC-curve, enter a given tensiometer reading and move vertically upward and intersect the SWC-curve, go left and read SWC for the soil profile.

Example:

Tensiometer reading = 48 centibars
$\therefore$ SWC = 3.7 inches

To determine how much to apply or the soil water deficiency, subtract the SWC from AWC.

$$F_n = SWD = AWC - SWC$$
$$= 5.90 - 3.70$$
$$= 2.20 \text{ inches}$$

In this example the SWC has not reached the MAD point which is set at about 2.95 inches (5.90 x 50/100 = 2.95). The irrigator can wait several days before he needs to irrigate.
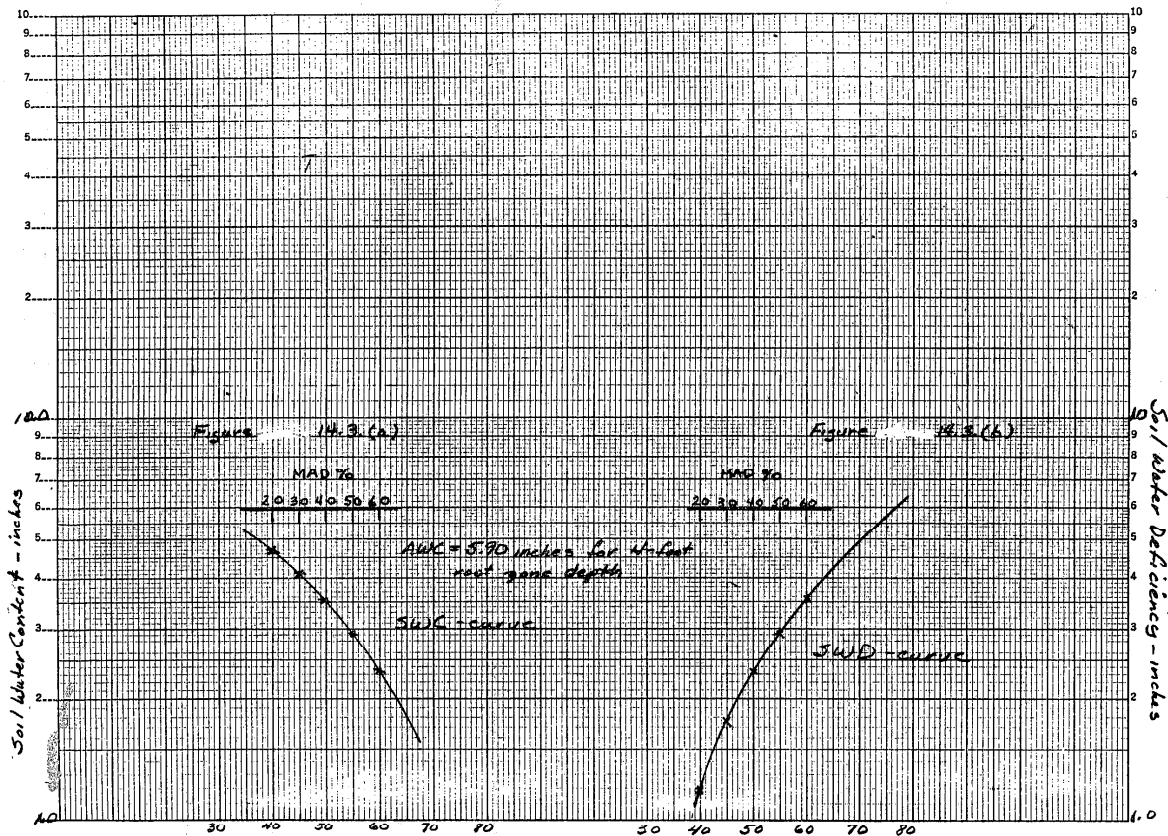
(c) As an alternative, plot soil water deficiency against tensiometer readings. Figure 14.3.(b) was developed for the data given. This gives an estimate of soil water deficiency directly.
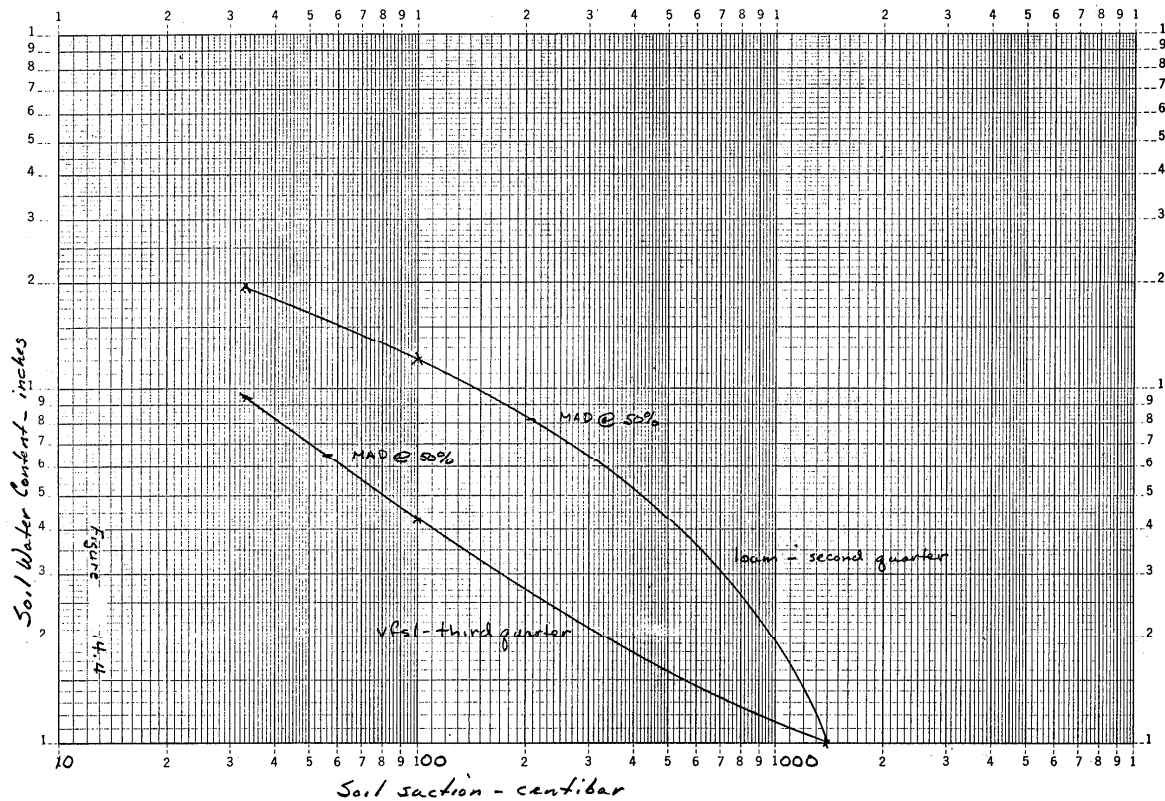
Example:

Tensiometer reading = 57 centibars
$\therefore$ SWD = 3.2 inches

In this case, MAD level has been exceeded and an irrigation is needed. The net amount to be applied (F_n) is 3.2 inches.

(d) Figure 14.4 was developed from the additional data which was collected. The second quarter of the root zone is a loam with

Figure 14.3.(a)

MAD %

20 30 40 50 60

AWC = 5.90 inches for 4-foot
root zone depth

SWC-curve

Figure 14.3.(b)

MAD %

20 30 40 50 60

SWD-curve

Soil Water Content - inches

Soil Water Deficiency - inches

Figure 4.2

Soil Water Content – inches

Soil suction – centibar

MAD @ 50%

MAD @ 50%

loam – second quarter

vfsl – third quarter

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a moderate water holding capacity. The third quarter is a very fine sandy loam with a low water holding capacity. From the study it was determined the soil profile would reach a 50 percent MAD level when the loam was at a SWC of 0.82 inches/foot and the vfsl at a SWC of 0.65 inches/foot. If the tensiometer in the second quarter was used to predict irrigation needs, the tensiometer would become inoperable because the soil suction would reach about 210 centibars before an irrigation is required. This tensiometer will be of little use because the suction will be broken between each irrigation. At the same time, the soil suction in the third quarter would reach about 56 centibars which is within the operating range of the tensiometer. Thus, the tensiometer in the third quarter should be used to predict when and how much to apply.

15. Electrical resistance blocks

a. Electrical resistivity can be used to measure a change in soil water content. The equipment used to measure changes in soil water content consists of a portable resistance meter and electrodes imbedded in small blocks.

b. The blocks consist of permanently embedded electrodes in materials such as nylon, fiberglass, or gypsum. The electrodes are attached to lead wires which are plugged into a meter. When the blocks are placed in contact with the soil, the moisture content of the block tends to equal the moisture content of the soil. Because the electrical resistance of the electrodes in the block varies with the moisture content, a measurement of electrical resistance by the meter is a good indication of the soil moisture content. The drier the soil, the greater the electrical resistance, and vice versa. This method will work satisfactorily in any soil that does not exhibit saline or alkaline problems.

c. The location and depth of installation of these blocks is the same as for tensiometers. The gypsum blocks should be placed in the soil, in the rooting zone of the crop as early in the season as is practical and left in the soil throughout the growing season. The following procedure is suggested for installing the blocks.

(1) The electrical resistance blocks should be thoroughly soaked in a pail of water before installing (follow manufacturer's recommendations for soaking time). Soaking removes air from the blocks and insures accurate readings of the soil moisture.

(2) A soil probe or auger can be used to bore a hole in the row slightly larger than the electrical resistance block. In row crops, the hole should be angled toward the furrow.

(3) The last 3 inches of soil removed from the hole should be crumbled and put back into the hole. About ½ cup of water should be poured into the hole so a slurry of mud is formed in the bottom.

(4)   The blocks should be pushed into the hole with the soil probe, or ½ inch diameter electrical conduit, setting them solidly in the bottom with a firm push of the probe.   Firm contact between the blocks and surrounding soil must be made.

(5)   The hole should then be filled with soil, 3 or 4 inches at a time, tamping the soil firmly as the hole is filled.

(6)   The wire leads from the blocks should be brought to a single station, midway between the holes and tied to a stake with the wires separated.   The wires should be color coded with colored plastic tubing or other means of identification.

d.   Electrical resistivity readings should be correlated with the soil water content for the soil profile at each station.   This can be done by using the gravimetric method in Paragraph 11.   Gravimetric measurements should be made for several different electrical resistivity readings and plotted on a graph.   Figure 15.1 shows an example of such a plotting.

e.   Irrigations should be scheduled when the meter readings from the most active root zone reach the desired level of soil water depletion using the graphs developed for a given site.

(1)   Guides have been developed for interpreting meter readings as they relate to soil water content which are given in Table 15.1.

(2)   Meter readings that indicate the need for irrigation will be different for various textured soils and MAD.   Table 15.2 gives a guide for irrigating corn and grain sorghum.

(3)   There will be differences in electrical resistance readings due to the frequency of the A.C. resistance meters.   Each company selling these meters for measuring soil water content has instructions which are provided with the meters.   Because of these problems, it is desirable to develop site specific graphs.

(4)   In using the guideline values in Table 15.2, irrigations should be started when the average meter readings from the shallow blocks reach the indicated readings.   Adjustments have been made in the recommended meter readings to allow for 5 to 8 days to completely irrigate all fields supplied by one water source.

f.   To determine when and how much water to apply requires the development of a relationship between resistivity readings and soil water content for the given soil profile.   An example of the development of this relationship and use is given in Paragraph 15.g.   The following procedure should be used to collect data.

(1)   Measure the soil water content in the root zone.   Record the resistivity or meter reading at time of soil water content measurements.

Table 15.1. INTERPRETATION OF READINGS ON THE
ELECTRICAL RESISTANCE METERS

| | Electrical resistance | | Interpretation |
	Ohms	Meter * Readings	
Nearly Saturated	Less then 200	200 to 180	Near saturated soil often occurs for a few hours following irrigation. Danger of water-logged soils, a high water table, poor soil aeration if reading persists for several days.
Field Capacity	300 to 500	180 to 170	Field Capacity. Irrigations discontinued in this range to prevent waste by deep percolation and leaching of nutrients below the root zone.
Irrigation Range	3200 to 7000	120 to 80	Usual range for starting irrigations. Soil aeration is assured in this range. Starting irrigations in this range insures maintaining readily available soil moisture at all times.
Dry	Above 7000	Less than 80	This is the stress range. However, crop not necessarily damaged or yield reduced. Some soil moisture is available to the plant but is getting dangerously low for maximum production.

*Indicative of soil conditions where the electrical resistance block is located. Judgment should be used to correlate these readings to general crop conditions in the field.

Table   15.2. ELECTRICAL RESISTANCE READINGS FOR
        STARTING IRRIGATION OF CORN AND GRAIN SORGHUM

Soil Texture	Meter readings on shallow block	
	Meter Reading	Electrical Resistance
		(Ohms)
Loamy sands Sandy loams	120	3200
Very fine sandy loams Silt loam	100	4800
Clay loams Silty clay loams	80	7000

Figure 15.1
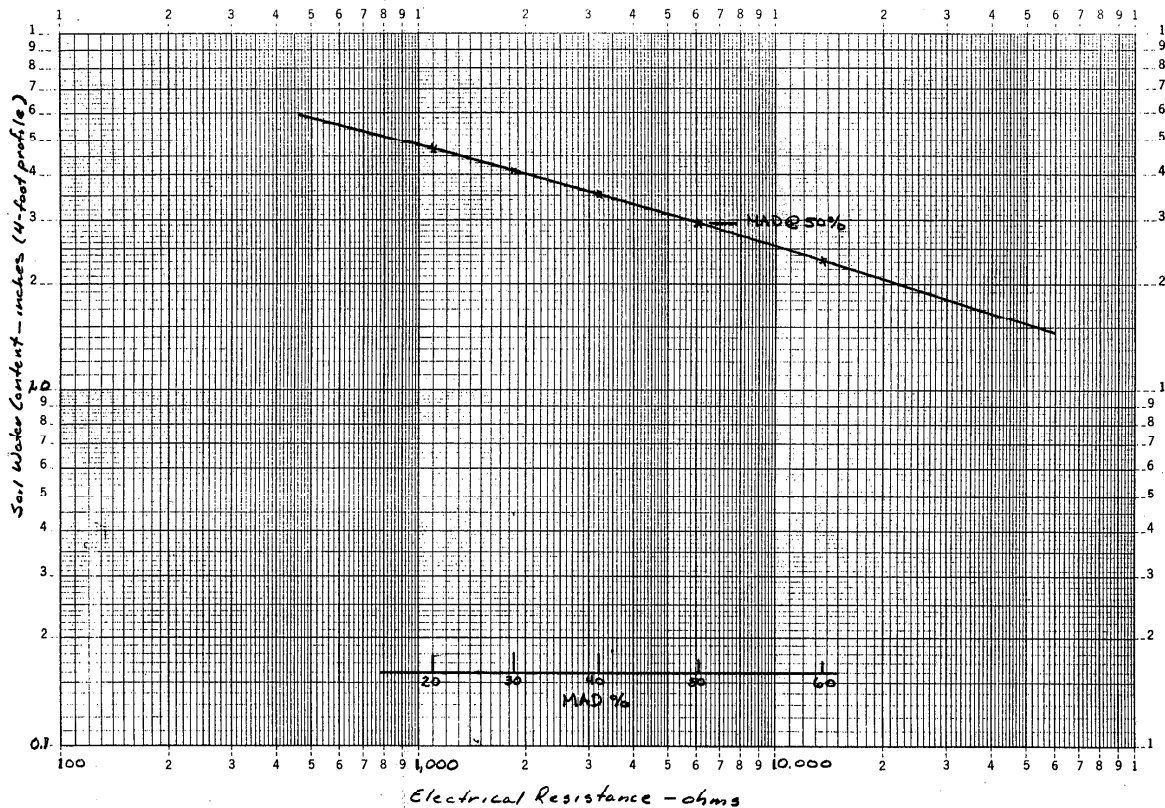
(2) Make a number of measurements at different resistivity readings.

(3) Plot the data on graph paper.

g. Example of developing a graph for estimating when and how much water to apply.

(1) Given

(a) Resistivity block in the second quarter of a 4-foot root zone.

(b) The following data was collected:

Soil Texture	Depth (inches)	AWC in/ft
loam	0-24	2.0
vfsl	24-48	0.95

Total AWC = 5.90 inches

Resistivity readings (ohms)	SWC for 4-foot profile (inches)
13,500	2.36
6,000	2.94
3,200	3.54
1,850	4.12
1,100	4.72

(2) Find

(a) Develop a graph to estimate the soil water content (SWC) for the 4-foot profile.

(b) Show how to use the graph to estimate when and how much to apply.

(3) Solution

(a) On graph paper (Logarithmic 2x3 cycle) plot SWC versus resistivity readings and connect the points. If necessary, extend the line to cover a range from field capacity to the MAD level set for the crop being irrigated. Indicate the MAD point on the graph. Figure 15.1 was developed for the given data. As an alternative, the soil water deficiency (SWD) can be plotted and the amount that needs to be applied can be read directly from the graph.

(b) To use the graph, enter a given resistivity reading and move vertically upward and intersect the curve, go left and read SWC for the soil profile.

Example:

Resistivity reading = 2200 ohms
.˙. SWC = 3.9 inches

To determine how much to apply subtract SWC from AWC.

$$F_n = AWC - SWC$$
$$= 5.90 - 3.90$$
$$= 2.0$$

In this example the SWC has not reached the MAD point which is about 2.95 inches. The irrigator can wait several days before he needs to irrigate.

IRRIGATION EVALUATION PROCEDURES

20. General

a. The effectiveness of a farmer's irrigation water management practices can be determined by making field observations and evaluations. The results of these observations and evaluations are used to help the irrigator improve his water management techniques and/or upgrade his irrigation system. These improvements should save money by conserving water and energy, reducing nutrient losses, and improving crop yields. The following principles apply to all irrigation methods.

(1) Irrigation should be made in a timely manner so as to maintain a favorable soil water content for good crop growth. An exception may be made where the water supply is limited. In this situation, water should be applied in a manner that will maximize net income.

(2) The amount of water applied should be sufficient to bring the root zone profile up to field capacity. Center pivots may have difficulty meeting this requirement during periods of high consumptive use.

(3) The water should be applied at a rate that will not cause waste, erosion, or pollution.

b. An examination of a farmer's irrigation water management practices, then, should attempt to answer the following questions.

(1) Are irrigations being applied in a timely manner?

(2) What is the soil moisture deficiency?

(3) How much water is being applied?

(4) Is the irrigation causing excessive erosion?

(5) How uniformly is the applied water spread over the field?

(6) How much of the water is infiltrated into the soil?

(7) Is there excessive deep percolation and/or runoff?

(8) If so, how much deep percolation and/or runoff?

(9) Is there a pollution problem being caused by irrigation?

(10) What is the application efficiency and the uniformity of application?

(11) On a sprinkler irrigated field, is there translocation or surface runoff?

c.   To answer some of the above questions, use should be made of the Irrigation Water Management sections on Irrigation Timing, Measuring Soil Water Content, and Procedures for Measuring Intake and Application Rates.

21. Border

a.   To make a border evaluation, the following data should be collected.

(1) Area being evaluated (length and width of border strip)

(2) Intake rate (This is optional. The family of intake curves can be used in the evaluation, Figure 22.4).

(3) Soil water content prior to irrigation

(4) Soil water content at field capacity

(5) Volume of inflow and outflow (time and flow rate)

(6) Rate of advance and recession

b.   To make the evaluation the following equipment is needed.

(1) Stakes, hatchet, and marking crayon

(2) Engineer's level, tripod, and rod

(3)   Measuring tape (100-foot)

(4)   Flow measuring devices

(5)   Cylinder intake equipment

(6)   Watch or clock

(7)   Shovel

(8)   Equipment for determining soil water content, e.g., soils auger, Speedy moisture meter kit, etc.

(9)   Field notebook and/or forms for recording data. Sample forms for recording data are shown in Figure 21.1. and Figure 21.2.

    c.   The following procedure should be used to collect data for evaluation.

(1)   Select one or more border strips which are representative of the field being evaluated. It is desirable to select a site which will permit measurement of runoff if it occurs.

(2)   Set stakes at 50- or 100-foot stations down the border and measure width of border strip.

(3)   Run levels in the border strip at each station to determine the average and variation in slope.

(4)   Install the necessary measuring devices to measure inflow and outflow if there is no existing way to measure flow.

(5)   Measure or estimate the soil water content before irrigation. Refer to the section on Measuring Soil Water Content.

(6)   Set up equipment for measurement of intake.   Refer to the section on Procedures for Measring Intake and Application Rates.

(7)   Irrigate with the flow rate normally used by the farmer and record start time.

(8)   At 5- to 10-minute intervals check the flow rate until it reaches a constant rate. Each time the flow is checked, record the flow rate and time of measurement. Periodically during the trial, check the flow rate and if different record the flow rate and time. If there is considerable fluctuation in the flow rate, frequent checks should be made.

(9)   Record the time the leading edge of the water reaches each station. If the leading edge is an irregular line across the border strip, average the time as different parts of the leading edge reach the station.

FURROW OR BORDER IRRIGATION FIELD EVALUATION WORKSHEET

Farm _____ Border or Furrow No. _____ Date _____

Inflow _____(gpm)(cfs) Water Off _____ T_i _____ min

SCD _____ Field _____ Crop _____

Inflow Data								Sta.	Elev. (ft)	Time water is on the land				Oppor- tunity Time T_{ox} (min) $T_r - T_a$	Depth Infiltrated	
Clock 1/ Time	Elapsed Time (min)	ΔT (min)	Gage H ( )	Flow Rate ( )	Average Flow Rate ( )	Volume ( )	Σ Volume ( )			Advance		Recession			Typical f (in)	Adjusted f_{adj} (in)
										Time 1/	Elapsed Time 2/ (min) T_a	Time 1/	Elapsed Time 2/ (min) T_r			

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as 1330
2/ After water is turned on at head of field

Figure 21.1

BORDER IRRIGATION EVALUATION

Farm _____ Field # _____ Date _____

Legal Description _____ By _____

Crop _____ Soil Series _____ AWC _____ I_f _____

Wetted border width _____ Length _____ Set Time _____ Stream Size _____

1. Depth of application needed, F_n = AWC - SWC

$$F_n = \text{_____ in} - \text{_____ in} = \text{_____ inches}$$

2. Gross depth of water applied, $F_g = Q \times T_i \div A$

A (area) = Length x wetted width/43,560 = acres

= _____ ft x _____ ft/43,560 ft²/ac _____ acres

F_g = _____ cfs x _____ hrs ÷ _____ ac = _____ inches

3. Minimum opportunity time, $T_{ox\ min}$ = _____ min @ Sta _____

4. Minimum depth infiltrated, $f_{adj\ min}$ = _____ inches (from adj curve)

5. Is an adequate irrigation obtained? Yes   No   (If $f_{adj\ min} > F_n$ = yes)

6. Ave. depth infiltrated, $F_{(o-L)adj}$ = _____ inches

7. Deep percolation, DP = $F_{(o-L)adj} - F_n$

DP = _____ in - _____ in = _____ inches

8. Volume of runoff, VRO = (Q x T) - $VF_{(o-L)adj}$

VRO = (_____ cfs x _____ hr) - (_____ in x _____ ac) = _____ ac-in

9. Uniformity of application, DU = $f_{adj\ min}/F_{(o-L)adj}$ x 100

DU = _____ in/_____ in x 100 = _____%

10. Application efficiency, AE = F_n/F_g x 100

AE = _____ in/_____ in x 100 = _____%

11. Actual application efficiency, AAE = (DU x AE)/100

AAE = (_____% x _____%)/100 = _____%

12. Required application time, $T_i = T_0 - T_L$

T_L = (time water disappears at Sta. 0+00) - (Time water off)

T_L = _____ hrs - _____ hrs = _____ (convert to minutes)

T_0 = _____ min (from adj curve for F_n)

T_i = _____ min - _____ min = _____ min

13. Recommendations:

Figure 21.2

(10) Record the time that runoff starts, if there is any. Periodically measure the flow rate and record the rate and time of measurement until it ceases.

(11) Record the time when water is turned off at the head end of the field. As the sheet of water recedes past each station record the time. This requires good judgment. On slopes of 0.5 percent or greater, a large part of the water remaining in the border strip when the supply is shut off may move down slope in a fairly uniform manner. On these fields, record recession time at each station when the water has disappeared from the area above it. If the recession line across the border strip is irregular, record the time when there is about as much cleared area below as there is water-covered area above the station. On slopes of less than 0.5 percent, a smaller proportion of the water moves down the strip. Some may be trapped in small depressions and may not be absorbed for some time after surrounding areas are clear. Since the important thing is to determine when the intake opportunity is essentially gone, the recession time usually may be recorded for a station when 80 to 90 percent of the area between it and the next station upstream has no water on the surface.

(12) Check the adequacy and uniformity of irrigation at a number of places with an auger or soil tube. Sandy soils can be checked in about 24 hours after irrigation and clayey soils should be checked about 48 hours after irrigation so that the gravitational water has drained.

(13) If it is necessary to establish the field capacity, determine the soil water content when checking the adequacy of irrigation.

(14) Example of border trial data is given in Paragraph 21.f.

d. The following procedure should be used to evaluate the border irrigation trial.

(1) Plot the accumulative intake curve. The procedure for plotting this data is given in the section on Procedures for Measuring Intake and Application Rates.

(2) Plot the advance and recession data on the same sheet (see Figure 21.4) of graph paper (10x10 to ½ or 1 inch) for each border strip. This is a plotting of time versus distance. If the runoff was not measured, for gradient borders, extend the advance and recession lines and close the end off. This extended area represents runoff. Refer to Figure 21.4 for an illustration.

(3) Compute the soil water deficit. This is the net depth of application (F_n) needed for the irrigation. Refer to Irrigation Timing, Paragraph 1 for computational procedure.

(4) Compute the gross depth of water applied.

$$F_g = QxT_i/A$$

Where:

F_g = gross depth, inches
Q = average inflow rate, cfs
T_i = inflow time, hours
A = area of border strip, acres

(5) Determine the opportunity time (T_{ox}) along the border strip, by subtracting the time of advance (T_a) from the time of recession (T_r) at each station. Record this on the advance-recession graph as shown in Figure 21.4 or on the work sheet Figure 21.3.

$$T_{ox} = T_r - T_a = \text{minutes}$$

Note the minimum opportunity time ($T_{ox\ min}$) at the station having the least opportunity time.

(6) Adjust the cumulative intake curve or the family cumulative intake curve for the gross depth applied (F_g). This is done in the following manner and is illustrated in the example given in Paragraph 21.f.

(a) For each station find the depth infiltrated f. This is done by using a cumulative intake curve. The cumulative intake curve can be developed from cylinders such as in Figure 21.5. These should be used when available. On the other hand, if cylinder trials are not available, use should be made of the curves in Figure 22.4. To select the appropriate curve, refer to the soils section of the irrigation guide for the intake family number for the appropriate soil series.

(b) Determine the typical average weighted depth infiltrated, $F_{(o-L)}$ or $F_{(o-Le)}$. The f values for Station 0+00, the last station for a whole segment, and the f value for a short segment must be prorated. If applicable, include the extended length of the border. The following equations can be used to determine $F_{(o-L)}$ or $F_{(o-L_e)}$.

$$F_{(o-L)} \text{ or } F_{(o-L_e)} \frac{fo}{2} + f_1 + f_2 \ldots + \frac{fn}{2} \frac{Ls}{(Le \text{ or } L)} + \frac{fn + fns}{2} \frac{Lss}{(Le \text{ or } L)}$$

$$F_{(o-L)} \text{ or } F_{(o-Le)} = \frac{fo}{2} + f_1 + f_2 \ldots + \frac{fn}{2} \frac{Ls}{(Le \text{ or } L)}$$

Where

$F_{(o-L)}$ = weighted average depth infiltrated for those border strips where the runoff is excluded or where no run off occured, inches

$F_{(o-L_e)}$ = weighted average depth infiltrated for those border strips where runoff occured but not measured and the border strip length was extended, inches

f_0 = typical depth infiltrated at Station 0+00, inches

f_1, f_2, etc. = typical depth infiltrated at other stations, inches

f_n = typical depth infiltrated at last station where the station

to station intervals are the same as for f_1, f_2, etc., inches

f_{ns} = typical depth infiltrated at the end station when the

interval from the next to last station and the last station

is less than the other stations, inches

L_s = length of interval between stations, feet

L_{ss} = length of short interval, feet

L = length between Station 0+00 and last station, feet

L_e = length between Station 0+00 and last station plus the

extended length, feet
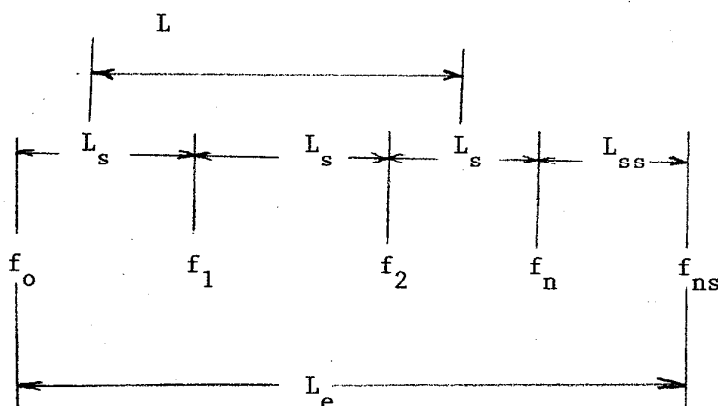
(c) Enter the typical weighted average depth infiltrated, $F_{(o-L)}$ or $F(o-L_e)$, on the left hand scale of the cumulative intake graph, move horizontally to the left and intersect the curve and mark this point.

(d) Calculate the depth applied to the border strip plus the extended area. Where there is no runoff the depth applied would be the gross depth applied, F_g as calculated in Paragraph 21.d.(4).

$$F_e = Q \times T_i/A$$

Where

F_e = depth applied to border with extended area, inches
Q = inflow rate, cfs
T_i = inflow time, hours
A = area of border strip including the extended area, acres

(e) Go to the cumulative intake curve at the point where $F_{(o-L)}$ or $F_{(o-L_e)}$ was established and move vertically upward or downward until the appropriate value for F_e or F_g on the left hand scale is intersected and mark this point.

(f) Draw a curve through the F_g or F_e point and parallel to the original curve. Label this new curve the "adjusted curve."

(7) Using the adjusted curve, determine adjusted f values and adjusted weighted average depth infiltrated $F_{(o-L)adj}$ or $F_{(o-L_e)adj}$. Use the same procedure as given in Paragraphs 21.d(6)(a) and 21.d(6)(b). The adjusted weighted average depth infiltrated should be equal or nearly equal to the depth applied, F_e, F_x, or F_g when there is no runoff, if the cumulative intake curve was correctly adjusted.

$$F_x = F_g - RO_a$$

Where F_x = average depth infiltrated into the border strip, inches
RO_a = actual measured runoff, inches

(8) From the advance-recession graph find the station with the minimum opportunity time ($T_{ox\ min}$). Do not consider extended area. For $T_{ox\ min}$ find the adjusted f value which gives the minimum depth infiltrated ($f_{adj\ min}$).

(9) Compare $f_{adj\ min}$ with F_n; if $f_{adj\ min}$ is greater than F_n, an adequate irrigation has been obtained. Any amount in excess of F_n has gone into deep percolation.

(10) In the case where $F_{(o-L_e)adj}$ was determined, an additional calculation is required to determine the adjusted average depth infiltrated, $F_{(o-L)adj}$, the border strip. To calculate $F_{(o-L)adj}$ use the equation in Paragraph 21.d(6)(b), but exclude the extended portion of the border strip.

(11) Determine the amount of deep percolation. This is the difference between the adjusted average depth infiltrated, $F_{(o-L)adj}$, and the depth of irrigation needed, F_n.

$$DP = F_{(o-L)adj} - F_n$$

Where

DP = deep percolation, inches

$F_{(o-L)adj}$ = adjusted average depth infiltrated, inches

F_n = depth of irrigation needed, inches

(12) Determine the volume of runoff. This is the difference between the amount applied and depth infiltrated.

$$VRO = (Q \times T_i) - V^F(o-L)adj$$

where

VRO = volume of runoff, ac-in

$V^F(o-L)adj$ = volume of water infiltrated, ac-in

= $F_{(o-L)adj} \times A$

Q = inflow rate, cfs

T_i = inflow time, hours

A = area of border strip, acres

(13) Determine the distribution uniformity. This is the minimum depth infiltrated ($f_{adj\,min}$) divided by the adjusted average depth infiltrated, $F_{(o-L)adj}$, times 100 to convert the ratio to percent.

$$DU = (f_{adj\,min}/F_{(o-L)adj})\,100 = \%$$

(14) Determine the application efficiency. The application efficiency (AE) is the depth of application needed (F_n) divided by the gross application depth (F_g) times 100 to convert the ratio to percent.

$$AE = (F_n/F_g)100 = \%$$

(15) Determine the actual application efficiency. The actual application efficiency (AAE) is the distribution uniformity multiplied by the application efficiency.

$$AAE = (DU \times AE)/100\%$$

(16) Determine the required opportunity time to infiltrate the amount of water needed (F_n) to replace the soil water deficit. This is done with the use of the cumulative intake curve. Enter F_n on the lefthand side, move horizontally until the adjusted curve is intersected. At this point move vertically downward and read the time; this is the required opportunity time (T_o).

(17) Determine the required application time (T_i). To determine the required application time requires an evaluation of the advance recession data. An example has been developed, Paragraph 21.f(3)(w) which provides a procedure for estimating the required application time.

e. Make necessary recommendations based on the evaluation. In making recommendations use should be made of NEH Section 15, Irrigation and other portions of the irrigation guide.

FURROW OR BORDER IRRIGATION FIELD EVALUATION WORKSHEET

Farm _____ Border or Furrow No. __4__ Date _____

Inflow __1.20__ (gpm)(cfs) Water Off __12:19__ T_i __88__ min

SCD _____ Field __#3__ Crop __Alfalfa__

	Inflow Data									Time water is on the land					Depth Infiltrated	
Clock Time	Elapsed Time (min)	ΔT (min)	Gage H ( )	Flow Rate ( )	Average Flow Rate ( )	Volume ( )	Σ Volume ( )	Sta.	Elev. (ft)	Advance Time	Advance Elapsed Time T_a (min)	Recession Time	Recession Elapsed Time T_r (min)	Opportunity Time T_{ox} (min) $T_r - T_a$	Typical f (in)	Adjusted f_{adj} (in)
								0+00	100.0	10:51	0	12:27	96	96	3.05	
								1+	99.8	10:59	8	12:59	128	120	3.55	5.15
								2+	99.6	11:21	30	13:18	147	116	3.50	5.00
								3+	99.5	11:26	35	13:29	152	123	3.60	5.20
								4+	99.4	11:41	50	13:33	162	112	3.40	4.90
								5+	99.3	11:59	68	13:38	167	99	3.15	4.55
								6+	99.1	12:18	87	13:44	173	86	2.85	4.10
								7+	99.0	12:40	109	13:45	174	65	2.40	3.40
								Extended length								
								8+						35	1.60	2.30
								8+50						10	0.70	1.00
														$F_{(a-le)} = 2.98''$		
														$F_{(a-le)adj} = 4.29''$		

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as 1330

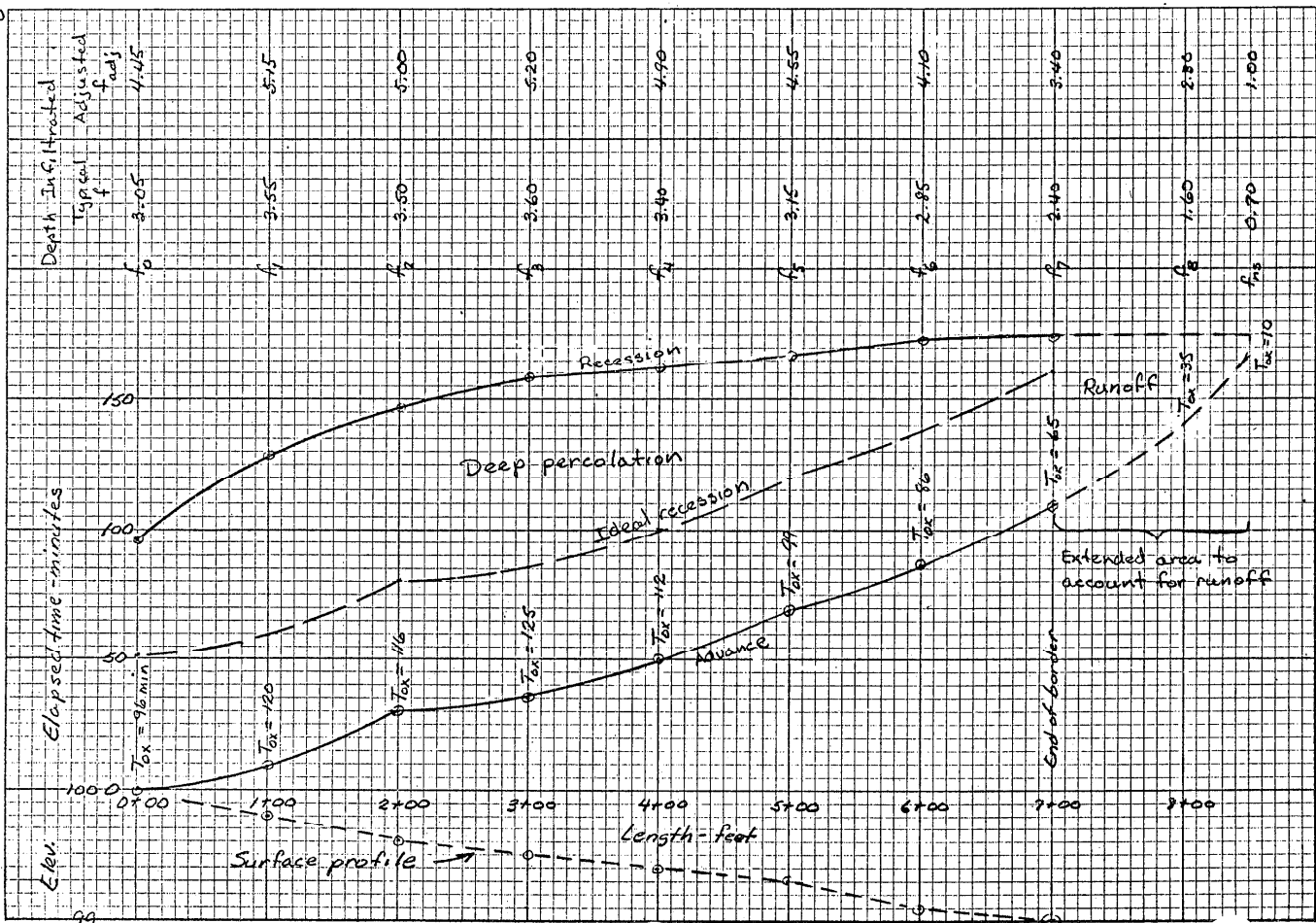2/ After water is turned on at head of field

Figure C1.2

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Figure 21.4

f. The following is an example of a border evaluation.

(1) Given

(a) Crop = alfalfa

(b) Cumulative intake curve which was developed from intake data, Figure 21.5

(c) Advance-recession data, Figure 21.3

(d) Soil water content (SWC) at time of evaluation = 3.1 in.

(e) Available soil water content (AWC) = 6 in.

(f) Border data

```
Q   = 1.2 cfs
T_i = 88 min.
width = 24 ft.
wetted width = 21 ft.
length = 700 ft.
```

(2) Find

(a) Evaluate border irrigation data

(b) Make recommendations

(3) Solution

(a) Use will be made of border evaluation form, Figure 21.2 which results in the filled out form Figure 21.6.

(b) Advance-recession data, Figure 21.3, was plotted on 10x10 to 1 inch graph paper, Figure 21.4. Advance-recession lines were extended, giving an extended border length of 150 feet.

(c) The net depth of application needed:

$$F_n = AWC - SWC$$
$$= 6.0 - 3.1$$
$$= 2.9 \text{ inches}$$

(d) Gross depth of application (F_g)

$$\text{Area} = (21 \text{ ft.} \times 700 \text{ ft})/43,560$$
$$= 0.34 \text{ acres}$$
$$F_g = Q \times T_i/A$$
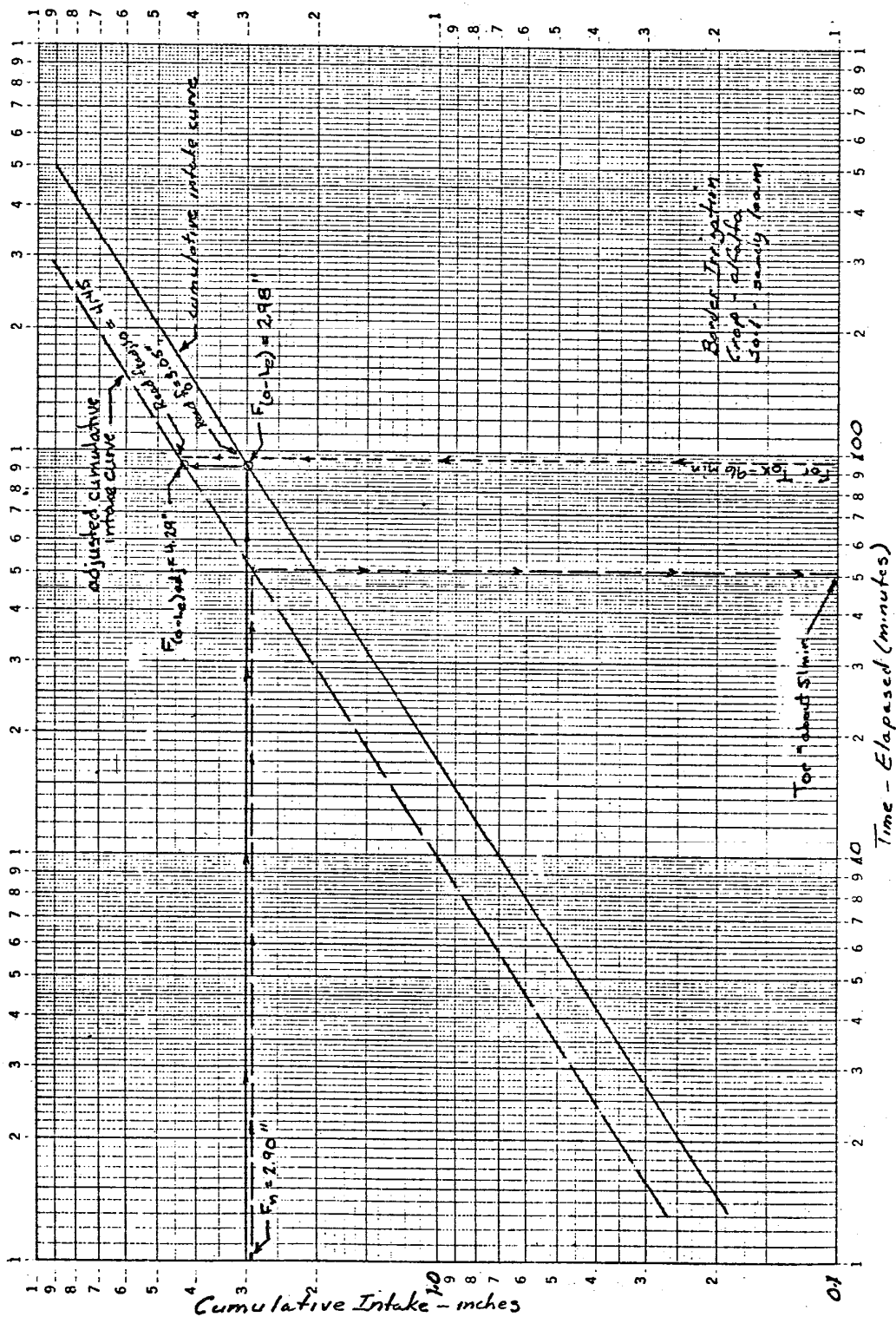$$= 1.2 \times (88/60)/.34$$
$$= 5.18 \text{ inches}$$

Figure   21.5

(e) Opportunity time (T_{ox}) determined for each station and extended area. Refer to Figure 21.3 or Figure 21.4.

(f) $T_{ox\ min}$ = 65 min at Station 7+00.

(g) Typical f was determined for each station using the cumulative intake curves, Figure 21.5 with an illustration showing F_o = 3.05 inches for T_{ox} = 96 min. The typical F values were recorded as shown in Figures 21.3 and 21.4. The F values need only be recorded in one place.

(h) Typical average weighted depth infiltrated, $F_{(o-L_e)}$

$$F_{(o-L_e)} = \frac{fo}{2} + f_1 + f_2 \ . \ . \ . \ + \frac{fn}{2} \quad \frac{Ls}{(Le)} + \frac{fn + fns}{2} \quad \frac{Lss}{(Le)}$$

where
f_0 = 3.05, f_1 = 3.55, f_2 = 3.50, f_3 = 3.60, f_4 = 3.40,
f_5 = 3.15, f_6 = 2.85, f_7 = 2.40, f_8 = f_n = 1.60
f_{ns} = 0.70
L_s = 100 ft.
L_{ss} = 50 ft.
L_e = 850 ft.

∴ $F_{(o-L_e)}$ = (((3.05/2)+3.55+3.50+3.60+3.40+3.15+2.85+2.40+(1.60/2)(100)+

(((1.60+0.70)/2)50/850)

= 2.98 inches

(i) 2.98 inches noted on graph, Figure 21.5

(j) Depth applied to the border plus extended area.

F_e = Q x T_i/A
= 1.20x(88/60)/((700+150)x21/43560)
= 4.29 inches

(k) On the graph, 4.29 inches was located above the 3.60 inches, Figure 21.5

(l) A parallel line was drawn to the original curve and labeled "adjusted cumulative intake curve."

(m) Adjusted f(fadj) was determined for each station using the adjusted cumulative intake curve, Figure 21.5 with an illustration showing $F_{(adj)o}$ = 4.45 inches for T_{ox} = 96 min. The adjusted F values were recorded as shown in Figures 21.3 and 21.4.

(n) Adjusted average weighted depth infiltrated.

$$F_{(o-L_e)adj} = \frac{fo}{2} + f_1 + f_2 \ldots + \frac{fn}{2} \; Ls + \frac{fn + fns}{2} \; Lss$$

where

$f_0 = 4.45$, $f_1 = 5.15$, $f_2 = 5.00$, $f_3 = 5.20$, $f_4 = 4.90$,
$f_5 = 4.55$, $f_6 = 4.10$, $f_7 = 3.40$, $f_8 = f_n = 2.30$
$f_{ns} = 1.00$
$L_s = 100$ ft.
$L_{ss} = 50$ ft.
$L_e = 850$ ft.

$$F_{(o-L_e)adj} = \frac{4.45}{2} + 5.15 + 5.00 + 5.20 + 4.90 + 4.55 + 4.10 + 3.40 + \frac{2.30}{2}\frac{100}{(850)} +$$

$$\frac{2.30 + 1.00}{2} \quad \frac{50}{(850)}$$

$$= 4.29 = Fe$$

(o) Minimum opportunity time and minimum depth infiltrated from adjusted curve.

$T_{ox \; min} = 65$ minutes, @ Sta. 7+00.

∴ $f_{adj \; min} = 3.40$ inches

(p) The depth of application needed for this irrigation was 2.90 inches, thus the field is over irrigated at point of minimum opportunity time.

(q) Adjusted average depth infiltrated, $F_{(o-L)adj}$, for the border strip.

$$F_{(o-L)adj} = \frac{fo}{2} + f_1 + f_2 \ldots + \frac{fn}{2} \left(\frac{Ls}{L}\right)$$

where

$f_0 = 4.45$, $f_1 = 5.15$, $f_2 = 5.00$, $f_3 = 5.20$, $f_4 = 4.90$,
$f_5 = 4.55$, $f_6 = 4.10$, $f_7 = f_n = 3.40$
$L = 700$
$L_s = 100$

$$F_{(o-L)adj} = \frac{4.45}{2} + 5.15 + 5.00 + 5.20 + 4.90 + 4.55 + 4.10 + \frac{3.40}{2}\frac{100}{700}$$

$$= 4.69 \text{ inches}$$

(r)   Deep percolation

$$DP = F_{(o-L)adj} - F_n$$
$$= 4.69 - 2.90$$
$$= 1.79 \text{ inches}$$

(s)   Volume of runoff

$$VRO = (Q \times T_i) - VF_{(o-L)adj}$$
$$= (1.20 \times (88/60)) - (4.69 \times (21 \times 700/43560))$$
$$= 0.18 \text{ ac-in}$$

(t)   Uniformity of application

$$DU = (f_{adj\ min}/F_{(o-L)adj})100$$
$$= (3.40/4.69) \times 100$$
$$= 72\%$$

(u)   Application efficiency

$$AE = (F_n/F_g)100$$
$$= (2.90/5.18) \times 100$$
$$= 56\%$$

(v)   Actual application efficiency

$$AAE = DU \times AE/100$$
$$= 73 \times 56/100$$
$$= 41\%$$

(w)   Required application time

<u>1</u> If no change is made in the rate of inflow, the required application time can be determined as follows:

<u>a</u> Determine the opportunity time required (T_{or}), apply the net depth of application (F_n using the adjusted cumulative intake curve, Figure 21.5. In this example, $F_n = 2.90$ in, thus T_{or} = about 51 min.

<u>b</u> At the station with the minimum opportunity time ($T_{ox\ min}$) add T_{or} to the advance time, T_a. This gives the minimum recession time ($T_{r\ min}$) should occur to provide an adequate irrigation for the flow rate used in the evaluation. In this case, $T_{ox\ min}$ occurs at Sta. 7+00 with $T_a = 109$ min, refer to Figure 21.3. The required recession time is approximately 160 min (109 + 51).

<u>c</u> Subtract the minimum recession time ($t_{r\ min}$) from the actual recession time (T_r) for the station which has minimum opportunity time. This gives the amount of time by which the inflow time (T_i) can be reduced. In this situation, the actual recession time at Sta. 7+00
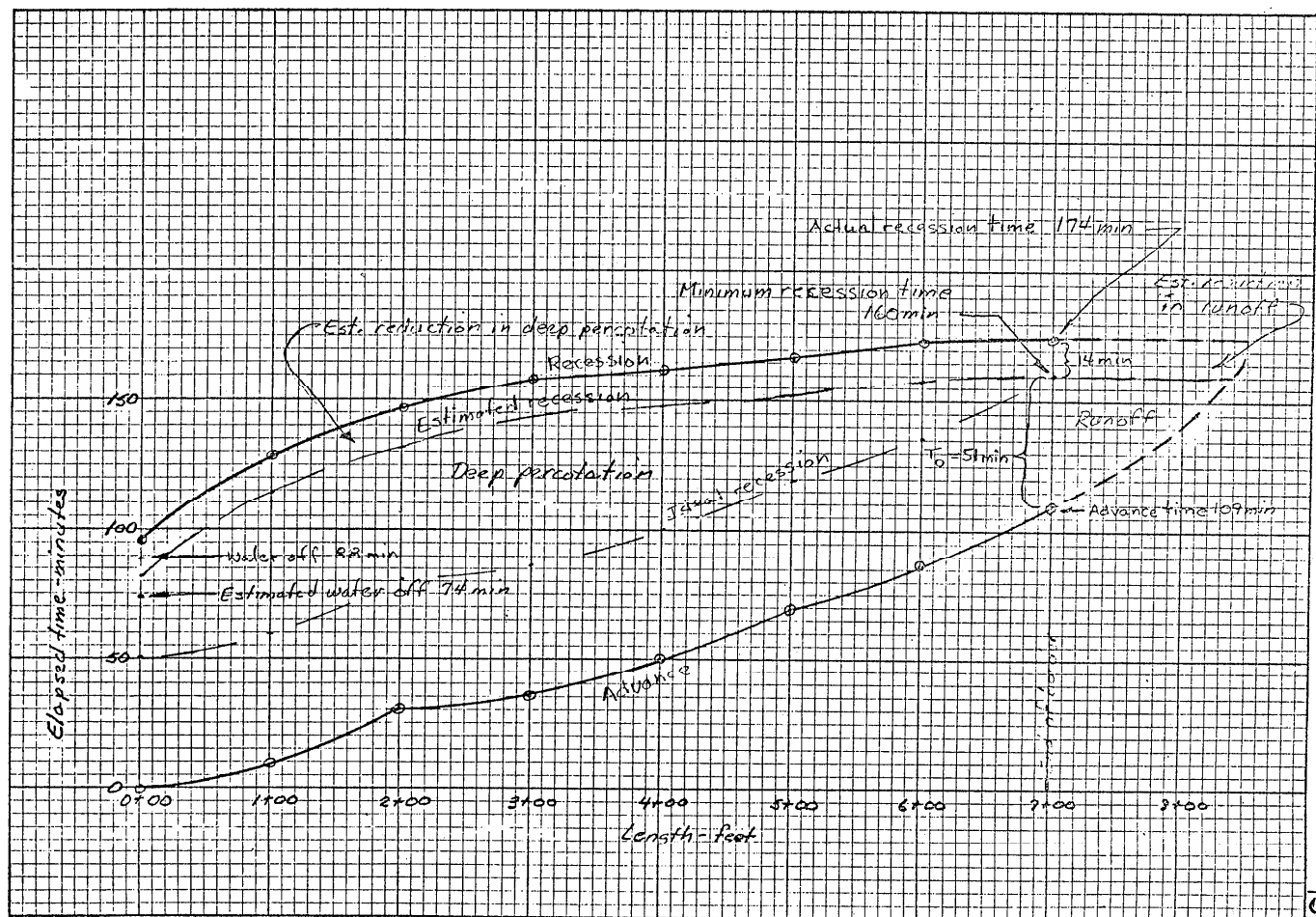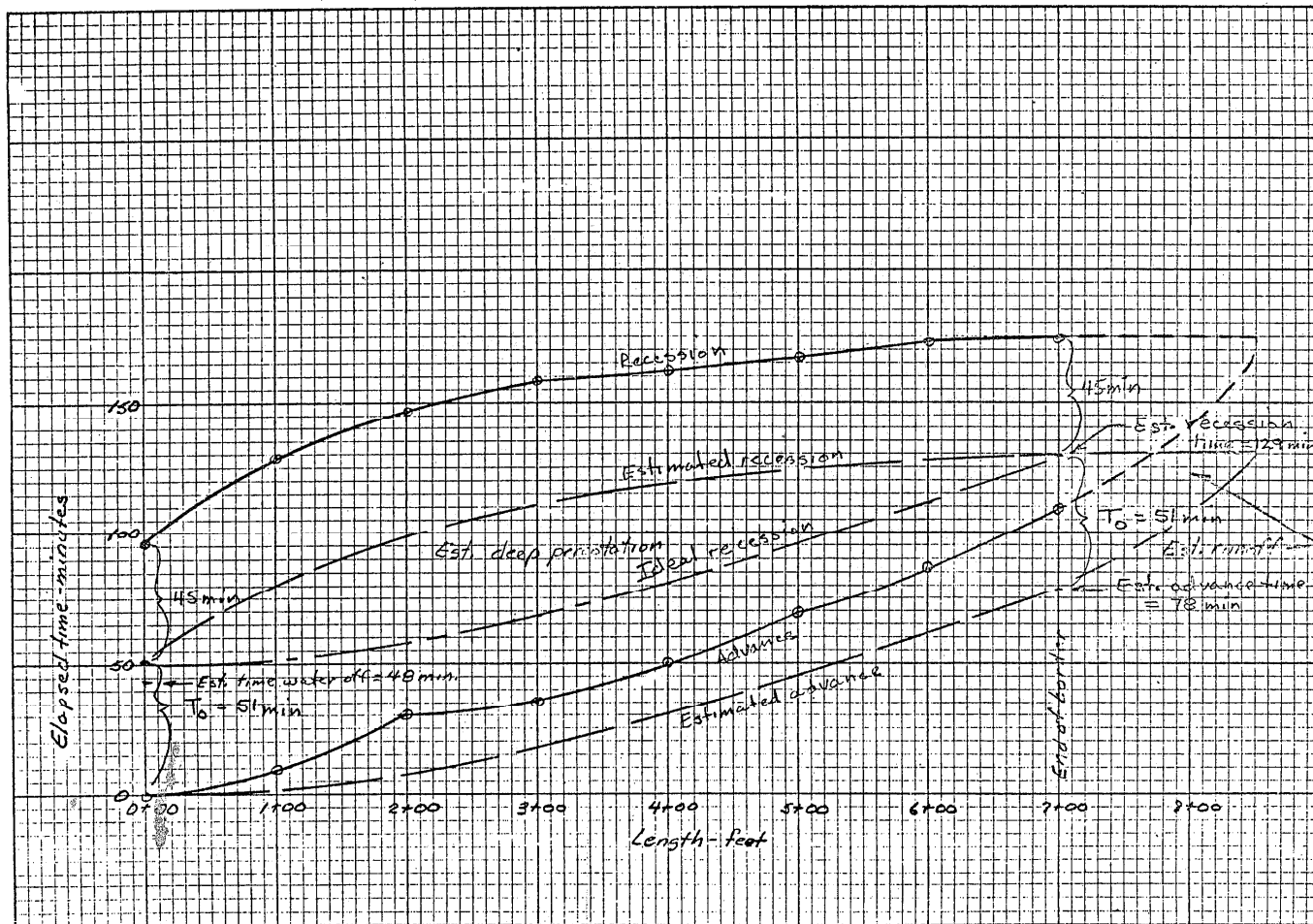
Figure 21.6

Actual recession time 174 min

Minimum recession time 160 min

Est. reduction in runoff

Est. reduction in deep percolation

Recession

Estimated recession

Deep percolation

Actual recession

14 min

$T_o = 51$ min

Runoff

Advance time 109 min

Water off 82 min

Estimated water off 74 min

150

100

50

0+00

Advance

Elapsed time—minutes

0+00 1+00 2+00 3+00 4+00 5+00 6+00 7+00 8+00

Length—feet

73

Figure 2.1.7

Elapsed time - minutes

150

100

45 min

50

Est. time water off = 48 min

T₀ = 51 min

0+00 1+00 2+00 3+00 4+00 5+00 6+00 7+00 8+00

Length - feet

Recession

Estimated recession

Est. deep percolation

Ideal recession

Advance

Estimated advance

45 min

Est. recession time = 129 min

T₀ = 51 min

Est. runoff

Est. advance time = 78 min

End of border

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Farm _____ _____ Field # _____ Date _____

Legal Description _____ By _____

Crop Alfalfa _____ Soil Series _____ AWC 6.0 in ____ I_f _____

Wetted border width 21 ft ____ Length 700 ft Set Time 88 min Stream Size 1.2 cfs

1. Depth of application needed, F_n = AWC – SWC

$$F_n = \underline{6.0}\ \text{in} - \underline{3.1}\ \text{in} = \underline{2.9}\ \text{inches}$$

2. Gross depth of water applied, F_g = Q x T_i ÷ A

 A (area) = Length x wetted width/43,560 = acres

$$= \underline{700}\ \text{ft} \times \underline{21}\ \text{ft/43,560 ft}^2/\text{ac} = \underline{0.34}\ \text{acres}$$

$$F_g = \underline{1.2}\ \text{cfs} \times \underline{(88/60)}\ \text{hrs} \div 0.34\ \text{ac} = \underline{5.18}\ \text{inches}$$

3. Minimum opportunity time, $T_{ox\ min}$ = __65__ min @ Sta 7+00

4. Minimum depth infiltrated, $f_{adj\ min}$ = __3.40__ inches (from adj curve)

5. Is an adequate irrigation obtained? (Yes) No   (If $f_{adj\ min}$ > F_n = yes)

6. Ave. depth infiltrated, $F_{(o-L)adj}$ = __4.69__ inches

7. Deep percolation, DP = $F_{(o-L)adj}$ – F_n

$$DP = \underline{4.69}\ \text{in} - \underline{2.9}\ \text{in} = \underline{1.79}\ \text{inches}$$

8. Volume of runoff, VRO = (Q x T) – $VF_{(o-L)adj}$

$$VRO = (\underline{1.20}\ \text{cfs} \times \underline{(88/60)}\ \text{hr}) - (\underline{4.69}\ \text{in} \times \underline{.34}\ \text{ac}) = \underline{0.18}\ \text{ac-in}$$

9. Uniformity of application, DU = $f_{adj\ min}/F_{(o-L)adj}$ x 100

$$DU = \underline{3.40}\ \text{in}/\underline{4.69}\ \text{in} \times 100 = \underline{72}\ \%$$

10. Application efficiency, AE = F_n/F_g x 100

$$AE = \underline{2.9}\ \text{in}/\underline{5.18}\ \text{in} \times 100 = \underline{56}\ \%$$

11. Actual application efficiency, AAE = (DU x AE)/100

$$AAE = (\underline{72}\ \% \times \underline{56}\ \%)/100 = \underline{40}\ \%$$

12. Required application time, T_i

T_L = (time water disappears at Sta. 0+00) – (Time water off)

T_L = 12:27 hrs – 12:19 hrs = 8 min (convert to minutes)

T_{op}= __51__ min (from adj curve for F_n)

T_i = __74__ min with no change in the inflow rate

13. Recommendations:

   see Paragraph   21.f(4)

is 174 min. The amount of time by which the inflow time can be reduced
is 14 min (174 - 160). The inflow time (t_i) is this case is 88 min and
should be reduced to about 74 min (88 - 14).

    d Figure 21.6 was prepared to show the expected changes in
recession and the impact on deep percolation and runoff. The ideal
recession curve represents the time needed to apply 2.90 inches in 51
min and the area between this curve and the recession curves represent
the deep percolation time. It should be noted that the deep percolation
and runoff can be reduced by changing the inflow time. To further
reduce the deep percolation, the inflow rate needs to be increases so as
to reduce the time required to advance the water. The next part shows a
procedure for estimating the time of advance and inflow time and the
impact of the change.

    2 The required application time can be determined as follows when
a change is made in the inflow rate.

    a Subtract the required opportunity time from the recession
time at Sta. 0+00. This provides an estimate of the time by which to
reduce the recession time at the station with the minimum opportunity
time ($T_{ox\ min}$). In the example, the required opportunity time to apply
2.90 in is about 51 min. The recession time at Sta. 0+00 is 96 min
refer to Figure 21.3. The amount of time by which the recession can be
reduced is 45 min (96 - 51). Station 7+00 has the minimum opportunity
time with a recession time of 174 min. The recession time could be
reduced to about 129 min (174 - 45).

    b Subtract the required opportunity time from the revised
recession time. This provides an estimate of the time the water should
reach the station with the minimum opportunity time. In this case, the
estimated advance time is about 78 min (129 - 51) at Sta. 7+00.

    c Determine the inflow rate which will advance the water in
the time determined in b. In order to determine the required flow rate,
several trials with different inflow rates may be needed to find which
one will advance the water in the required time.

    d To determine the required inflow time (T_i), subtract the
lag time ($\bar{T}_L$) from the required opportunity time at Sta. 0+00. In this
example, the lag time is as follows:

T_L = (time water disappears at Sta. 0+00) - (time water off)

    = 12:27 - 12:19

    = 8 min

To apply 2.90 inches requires an opportunity time (T_o) of about 51 min.

$$T_i = T_o - T_L$$

$$= 51 - 8$$

$$= 43 \text{ min}$$

e Figure 21.7 was prepared to illustrate the expected changes in recession and advance and the impact on deep percolation and runoff. By an increase in the inflow rate and a reduction in inflow time, there should be a decrease in deep percolation and runoff.

(4) Recommendations

The inflow time (T_i) should be reduced to about 43 min and the inflow rate increased so as to advance the water at a faster rate. This will provide a more uniform opportunity time and should reduce the deep percolation and runoff.

22. Furrow and Corrugation

     a.   To make a furrow or corrugation evaluation the following data should be collected.

        (1) Area being evaluated (length and width of furrows)

        (2) Intake rate (This is optional. The family of intake curves can be used in the evaluation, Figure 22.4.)

        (3) Soil water content prior to irrigation

        (4) Soil water content at field capacity

        (5) Volume of inflow and out-flow (time and flow rate)

        (6) Rate of advance and recession

     b.   The following equipment is needed to collect the data.

        (1) Stakes, hatchet, and marking crayon

        (2) Engineer's level, tripod, and rod

        (3) Measuring tape (100-foot)

        (4) Flow measuring devices.

        (5) Watch or clock

        (6) Shovel

        (7) Equipment for measuring soil water content e.g. soils auger, speedy moisture meter kit, etc.

        (8) Field notebook and/or forms for recording data. Sample forms for recording data are shown in Figure 21.1 and Figure 22.1.

     c.   The following procedure should be used to collect data for evaluation.

        (1) Select a site which is representative of the field being evaluated. It is desirable to select a site which will permit measurement of runoff if it occurs.

        (2) Select a minimum of three furrows for evaluation. Buffer or guard furrows are needed on each side of the selected furrows. It is desirable to evaluate the entire set, measuring the total inflow and outflow. Advance measurements can be made on several selected furrows.

FURROW IRRIGATION EVALUATION

Farm _____ _____ Field # _____ Date _____

Legal Description _____ By _____

Crop _____ Soil Series _____ AWC _____ I_f _____

Furrow width _____ Length _____ Set Time ._____ Stream Size _____

1. Depth of application needed, F_n = AWC - SWC

    $$F_n = \text{_____ in - _____ in = _____ inches}$$

2. Gross depth of water applied, $F_g = 1.6041\, QT_i/WL$

    F_g = 1.6041 x _____ gpm x _____ min/(_____ ft x _____ ft)

    = _____ inches

3. Minimum opportunity time, $T_{ox\ min}$ = _____ min @ Sta _____

4. Minimum depth infiltrated, $f_{adj\ min}$ = _____ inches (from adj curve)

5. Is an adequate irrigation obtained? Yes   No   (If $f_{adj\ min} > F_n$ = yes)

6. Ave. depth infiltrated, $F_{(o-L)adj}$ = _____ inches

7. Deep percolation, DP = $F_{(o-L)adj} - F_n$

    DP = _____ in - _____ in = _____ inches

8. Volume of runoff, VRO = $(QT_i/448.83) - VF_{(o-L)adj}$

    VRO = (_____ gpm x _____ hrs ÷ 448.83) -

    (_____ in x (_____ ft x _____ ft/43560)) = _____ ac-in

9. Uniformity of application, DU = $f_{adj\ min}/F_{(o-L)adj}$ x 100

    DU = _____ in/_____ in x 100 = _____%

10. Application efficiency, AE = F_n/F_g x 100

    AE = _____ in/_____ in x 100 = _____%

11. Actual application efficiency, AAE = (DU x AE)/100

    AAE = (_____% x _____%)/100 = _____%

12. Required application time, T_i

    T_a = _____ min

    T_L = (time water disappears at Sta. 0+00) - (Time water off)

    T_L = _____ hrs - _____ hrs = _____ (convert to minutes)

    T_o = _____ min (from adj curve for F_n)

    T_i = _____ min

13. Recommendations:

Figure   22.1

(3) Set stakes at 50- or 100-foot intervals down the field, starting with 0+00 at the head end.

(4) Run levels in the furrow at each station to determine the average slope and variation in slope.

(5) Set measuring devices at the head end of the field. If tail water will occur, set measuring devices at end of field.

(6) If part of the data collection is to include intake measurements set the necessary measuring devices at selected stations. For furrow intake measurements refer to the section on Procedures for Measuring Intake and Application Rates, Paragraph 32.

(7) Determine the soil water content and depth of water needed to fill the root zone. Refer to the section titled Measuring Soil Water Content for procedure.

(8) Begin irrigation with a typical flow rate used by the farmer and record start time.

(9) At 5- to 10-minute intervals check the flow rate until it reaches a constant rate. Each time the flow is checked, record the flow rate and time of measurement. Periodically during the trial, check the flow rate and if different record the flow rate and time. If there is considerable fluctuation in the flow rate, frequent checks should be made.

(10) Inspect each furrow for erosion or overtopping and estimate the maximum allowable stream. Flowing water nearly always causes some erosion, so cloudiness in the water for the first 5 minutes after a stream passes a point may be permissible. Obvious movement of soil particles and vertical cutting or undercutting along the furrow banks after the initial wetting would be serious erosion. This indicates a need for using a smaller stream.

(11) Record the time the leading edge of the water reaches each station.

(12) Record the time runoff starts, if there is any. Periodically measure the flow rate and record the rate and time of measurement until it ceases.

(13) Record the time when water is turned off at the head end of the field. Record the time when the water disappears at the head end and at the lower end.

(14) Check the cross-sectional wetting pattern, adequacy, and uniformity of irrigation at a number of places, down the entire length of the furrow, with a soil auger or soil probe. Sandy soils should be

checked about 24 hours after irrigation and clayey soils should be checked about 48 hours after irrigation so that gravitational water has drained.

(15)   Example of furrow trial is given in Paragraph 22.f.

d.   The following procedure should be used to evaluate the furrow irrigation trial.

(1)   Plot the accumulative intake curve. The procedure for plotting this data is given in the section on Procedures for Measuring Intake and Application Rates.

(2)   Plot the advance data on graph paper (10 x 10 to ½ or 1 inch) refer to Figure 22.2. On the same sheet, plot the elapsed time for when the water disappeared at the upper and lower end. Draw a line through the two points. This is the recession curve. This is a plotting of time versus distance. If the runoff was not measured extend the advance and recession lines and close the end off. The extended area represents runoff. Refer to Figure 22.2 for an illustration.

(3)   Compute the soil water deficit. This is the net depth of application (F_n) needed for the irrigation. Refer to the section on Irrigation Timing, Paragraph 2 for computational procedure.

(4)   Compute the gross depth of water applied

$$F_g = 1.6041 \ QT_i/WL$$

where

F_g = gross depth, inches
Q = inflow, gpm
T_i = inflow time, minutes
W = effective furrow width, feet
L = furrow length, feet

(5)   Determine the opportunity time (T_{ox}) along the furrow, by subtracting the time of advance (T_a) from the time of recession (T_r) at each station. Record this on the advance-recession graph as shown in Figure 22.2 or on the work sheet, Figure 22.3.

$$T_{ox} = T_r - T_a = \text{minutes}$$

Note the minimum opportunity time ($T_{ox \ min}$) at the station having the shortest opportunity time.

(6) Adjust the cumulative intake curve or the family cumulative intake curve for the gross depth applied (F_g). This is done in the following manner and illustrated in the example given in Paragraph 22.f.

(a) For each station determine the depth infiltrated, f. This is done by using the cumulative intake curve, Figure 22.4 or one that was developed from actual field data. For each station, enter T_{ox} on the horizontal scale, move upward and intersect the cumulative intake curve, go left and read the intake depth applied (f or f_{adj}). This value is then noted on the advance-recession graph or work sheet.

(b) Determine the typical average weighted depth infiltrated, $F_{(o-L)}$ or $F_{(o-L_e)}$. The f values for Station 0+00, the last station for a whole segment (i.e. 9+00), and the f value for a short segment (i.e. 9+50) must be prorated. If applicable, include the extended length of the furrow. The following equation can be used to determine the average weighted depth infiltrated, $F_{(o-L)}$ or $F_{(o-Le)}$.

$$F_{(o-L)} \text{ or } F_{(o-L_e)} = \frac{fo}{2} + f_1 + f_2 \cdots + \frac{fn}{2}\ \frac{Ls}{(Le \text{ or } L)} + \frac{fn + fns}{2}\ \frac{Lss}{(Le \text{ or } L)}$$

for 100-foot lengths plus some odd length, i.e. 825, 929, etc.

or

$$F_{(o-L)} \text{ or } F_{(o-L_e)} = \frac{fo}{2} + f_1 + f_2 \cdots + \frac{fn}{2}\ \frac{Ls}{(Le \text{ or } L)}$$

for 100-foot lengths, i.e. 500, 800, etc.

Where

$F_{(o-L)}$ = typical weighted average depth infiltrated for those furrows where the runoff was measured or where no run off occurred, inches

$F_{(o-L_e)}$ = typical weighted average depth infiltrated for those furrows where runoff occurred but not measured and the border strip length was extented, inches

f_0 = typical depth infiltrated at Station 0+00, inches

f_1, f_2, etc. = typical depth infiltrated at other stations, inches

f_n = typical depth infiltrated at last station where the station to station intervals are the same as for f_1, f_2, etc., inches

f_{ns} = typical depth infiltrated at the end station when the interval from the next to last station and the last station is less than the other stations, inches

L_s = length of interval between stations, feet

L_{ss} = length of short interval, feet

L_{ss} = length between Station 0+00 and last station, feet

L_e = length between Station 0+00 and last station plus the extended length, feet

$$L$$

$$L_s \qquad L_s \qquad L_s \qquad L_{ss}$$

$$F_o \qquad f_1 \qquad f_2 \qquad f_n \qquad f_{ns}$$

$$L \text{ or } L_e$$
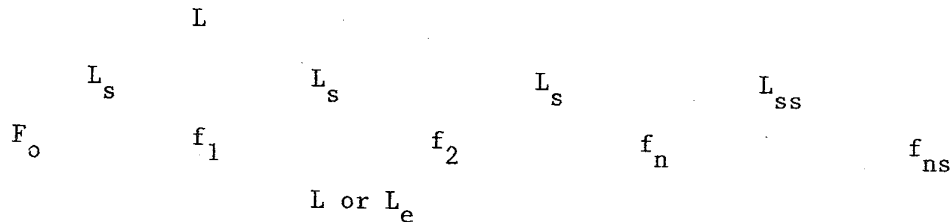
(c) Enter the typical weighted average depth infiltrated (f_{ave}) on the left hand scale of the cumulative intake graph or family intake curve at the appropriate depth, move horizontally to the right and intersect the curve and mark this point.

(d) Calculate the depth applied to the furrow plus the extended area (F_e). Where there is no runoff the depth applied would be the gross depth applied (F_g), as calculated in Paragraph 22.d.(4).

$$F_e = 1.6041 \, QT_i/WL_e \text{ or } L$$

where

F_e = depth applied to furrow which includes the extended area, inches

Q = inflow rate, gpm
T_i = inflow time, minutes
W = effective furrow width, feet
L or L_e = length (see Paragraph 22.d.(6).(b)), feet

(e) Take F_e or F_g to the cumulative intake curve and at the point where $F_{(o-L)}$ or $F_{(o-Le)}$ was established, move vertically up or down and intersect the appropriate value on the left hand scale and mark this point.

(f) Draw a curve through the F_e or F_g point which is parallel to the original curve. Label this new curve the "adjusted curve".

(8) Using the previously determined T_{ox} values and the adjusted curve, determine the adjusted depth infiltrated (f_{adj}) values and the adjusted weighted average depth infiltrated ($F_{(o-L)adj}$ or $F_{(o-L_e)adj}$) value. Use the same procedure as given in Paragraph 22.d.(6)(b). The adjusted weighted average depth should be equal or nearly equal to the depth applied, F_e, or F_x, or F_o when no runoff occurs, if the cumulative intake curve was correctly adjusted.

$$F_x = F_g - RO_a$$

Where

F_x = average depth infiltrated into the furrow, inches
RO_a = actual measured runoff, inches

(9) From the advance recession graph find the station with minimum opportunity time ($T_{ox\ min}$). Do not consider the extended area. For $T_{ox\ min}$ find the adjusted f value which gives the minimum depth of infiltration ($f_{adj\ min}$).

(10) Compare $f_{adj\ min}$ with F_n; if $f_{adj\ min}$ is greater than F_n an adequate arrigation has been obtained. Any amount in excess of F_n has gone into deep percolation.

(11) In the case where $F_{(o-Le)adj}$ was determined, an additional calculation is required to determine the adjusted average depth infiltrated, $F_{(o-L)adj}$, the furrow. To calculate $F_{(o-L)adj}$ use the same procedure as given in Paragraph 22.d.(6).(b), but exclude the extended portion of the furrow.

(12) Determine the amount of deep percolation.

$$DP = F_{(o-L)adj} - F_n$$

where

DP = amount of deep percolation, inches
$F_{(o-L)adj}$ = adjusted average depth infiltrated, inches   Fn = depth of irrigation needed, inches

(13) Determine the volume of runoff.

$$VRO = (QT_i/448.83) - VF_{(o-L)adj}$$

where

VRO = volume of runoff, ac-in

$VF_{(o-L)adj}$ $\equiv$ volume infiltrated, ac-in $F_{(o-L)adj}$ x A

Q $\equiv$ inflow rate, gpm T_i = time, hours
A $\equiv$ area of furrow, acres

(14) Determine the uniformity of application.

$$DU = f_{adg\ min}/F_{(o-L)adj}) \ 100 = \%$$

(15) Determine the application efficiency.

$$AE = (F_n/F_g) \ 100 = \%$$

(16) Determine the actual application efficiency. The actual application efficiency (AAE) is the uniformity of application multiplied by the application efficiency.

$$AAE = (DU \ x \ AE) \ 100 = \%$$

(17) Determine the required application time (T_i) to infiltrate the amount of water needed (F_n) to replace the soil water deficit. To determine the required application time requires an evaluation of the advance-recession data. An example has been developed, Paragraph 22.f(3)(4), which provides a procedure for estimating the required application time.

e.   Make necessary recommendations based on the evaluation. In making recommendations use should be made of NEH Section 15, Irrigation and other portions of the irrigation guide.

f.   The following is an example of a furrow evaluation.

(1)   Given

(a)   Crop = corn

(b)   The soil series, on which furrows are being evaluated is in the 0.25 intake family. The curve from Figure 22.4, for 0.25 intake family was transfered to 2 x 3 cycle log paper to serve as a worksheet, Figure 22.5.

(c)   Advance-recession data, Figure 22.3.

(d)   Soil water content (SWC) at time of irrigation, 2.5 inches

(e)   Available soil water content (AWC); 5.0 inches

(f)   Furrow data

effective furrow width (W) = 3.0 ft
length = 650 ft

(2)   Find

(a)   Evaluate furrow irrigation data

(b)   Make recommendations

(3)   Solution

(a)   Use will be made of Furrow Irrigation Evaluation form, Figure 22.1 which is snown completed in Figure 22.6.

(b)   Advance-recession data (Figure 22.3) was plotted on 10 x 10 to ½-inch graph paper, Figure 22.2. Advance and recession lines were extended, giving an extended furrow length of 900 feet.
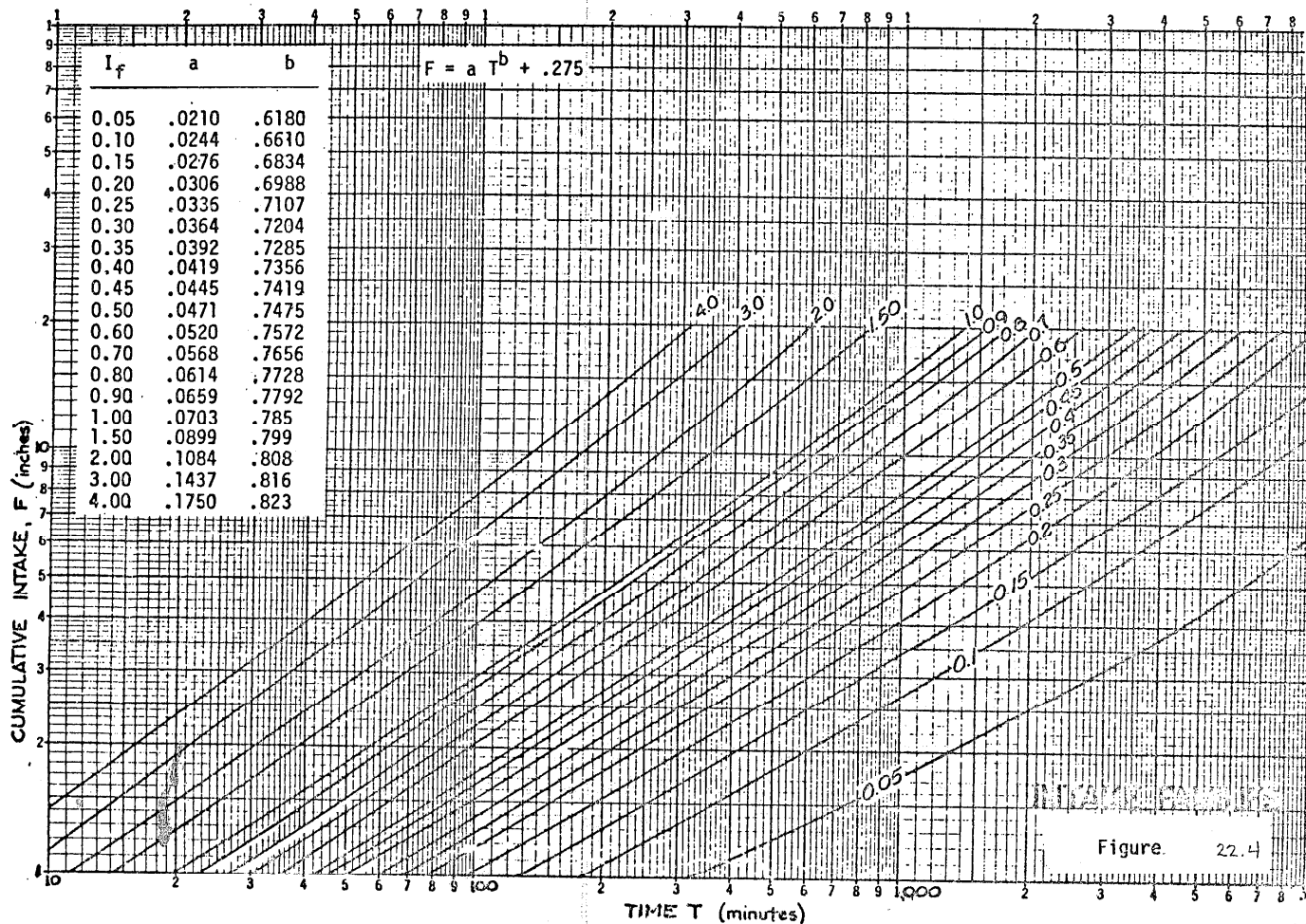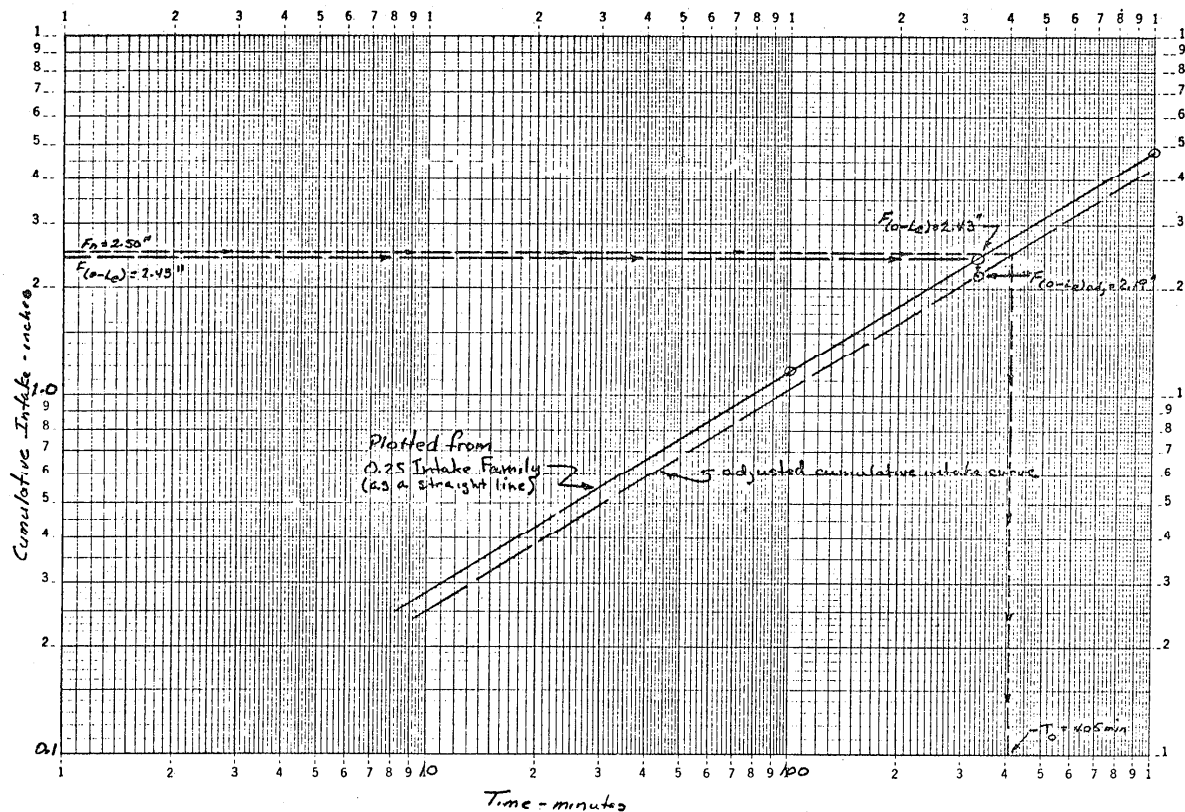
(c)   The net depth of application needed.

Figure 22.2
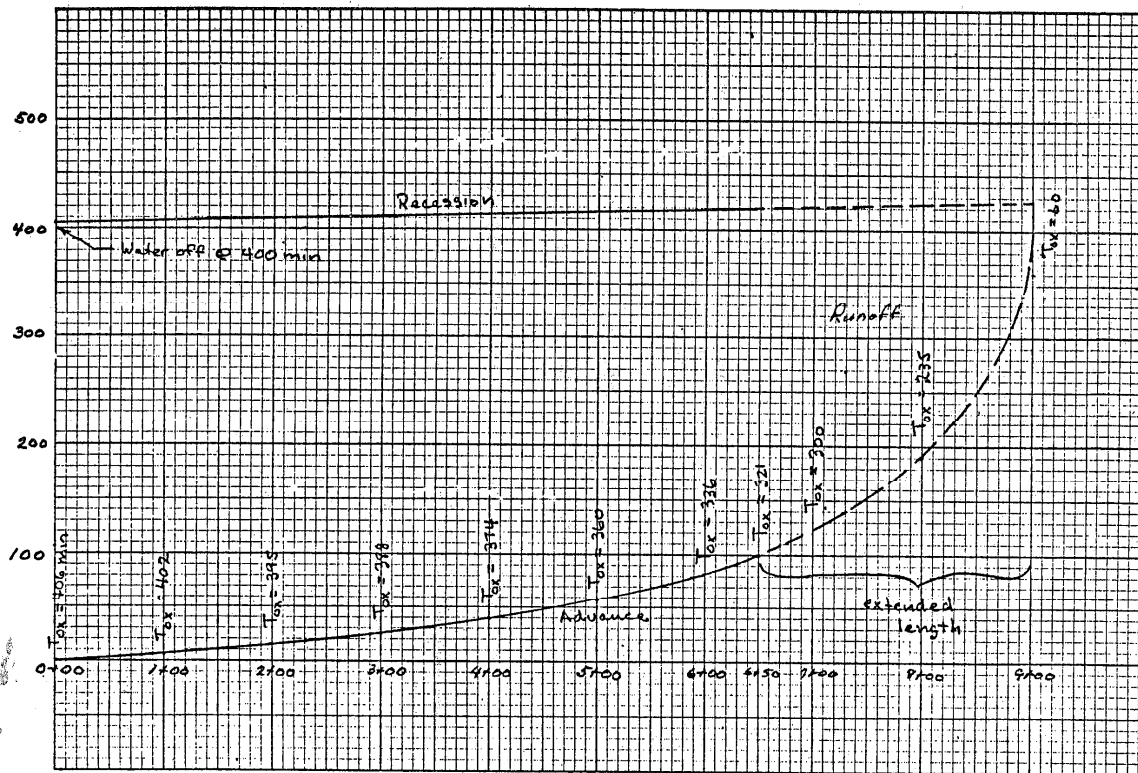
FURROW ~~OR BORDER~~ IRRIGATION FIELD EVALUATION WORKSHEET

Farm _____ ~~Border or~~ Furrow No. __A-6__ Date _____

Inflow· __9.2__ (gpm)~~(cfs)~~ Water Off __15:04__ T_i __400__ min

SCD _____ Field __#1__ Crop __Beets__

Inflow Data										Time water is on the land					Depth Infiltrated	
										Advance		Recession		Oppor-tunity Time T_{ox} (min) $T_r - T_a$		
Clock 1/ Time	Elapsed Time (min)	ΔT (min)	Gage H ( )	Flow Rate ( )	Average Flow Rate ( )	Volume ( )	Σ Volume ( )	Sta.	Elev. (ft)	Time 1/	Elapsed Time 2/ (min) T_a	Time 1/	Elapsed Time 2/ (min) T_r		Typical f (in)	Adjusted f_{adj} (in)
								0+00		8:24	0	15:10	426	426	2.75	2.50
								1+00		8:31	7			402	2.75	2.50
								2+00		8:39	15			395	2.70	2.45
								3+00		8:50	26	These values		388	2.70	2.40
								4+00		9:03	39	taken from graph		374	2.60	2.35
								5+00		9:22	58	Figure-6.22.5		360	2.55	2.30
								6+00		9:46	82			336	2.45	2.20
								6+50		10:03	99	15:24	420	321	2.40	2.15
								Extended length								
								7+00				These values taken from graph		300	2.30	2.05
								8+00						235	2.00	1.80
								9+00						60	0.85	0.75

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as. 1330
2/ After water is turned on at head of field

Figure 22.3

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Figure 22.4

I_f	a	b
0.05	.0210	.6180
0.10	.0244	.6610
0.15	.0276	.6834
0.20	.0306	.6988
0.25	.0335	.7107
0.30	.0364	.7204
0.35	.0392	.7285
0.40	.0419	.7356
0.45	.0445	.7419
0.50	.0471	.7475
0.60	.0520	.7572
0.70	.0568	.7656
0.80	.0614	.7728
0.90	.0659	.7792
1.00	.0703	.785
1.50	.0899	.799
2.00	.1084	.808
3.00	.1437	.816
4.00	.1750	.823

$$F = a\,T^b + .275$$

CUMULATIVE INTAKE, F (inches)

TIME T (minutes)

Figure 12.5

$$F_n = AWC - SWC$$
$$= 5.0 - 2.5$$
$$= 2.5 \text{ inches}$$

(d) Gross depth of application (F_g)

$$Fg = (1.6041 \ QT_i) \ / \ (WL)$$
$$= (1.6041 \times 9.2 \times 400) \ / \ (3.0 \times 650)$$
$$= 3.03 \text{ inches}$$

(e) Opportunity time (T_{ox}) determined for each station and extended area. Refer to Figure 22.3.

(f) Minimum opportunity time ($T_{ox \ min}$) is 321 min at Sta. 6+50

(g) Typical f was determined for each station and are shower in Figure 22.3.

(h) Typical average weighted depth infiltrated, $F_{(o-L_e)}$

$$F_{(o-L_e)} = \frac{fo}{2} + f_1 + f_2 \ . \ . \ . \ + \frac{fn}{2} \ \frac{Ls}{(Le)}$$

where

$$f_0 = 2.75, \ f_1, \ = 2.75, \ f_2 = 2.70, \ f_3 = 2.70, \ f_4 = 2.60,$$
$$f_5 = 2.55, \ f_6 = 2.45, \ f_7 = 2.30, \ f_8 = 2.00, \ f_9 = f_n = 0.85$$

(Note: f for station 6 + 50 was not included)

$$L_e = 900$$
$$L_s = 100$$

$$\therefore F_{(o-L_e)} = ((2.75/2) + 2.75 + 2.70 + 2.70 + 2.60 + 2.55 + 2.45 + 2.30 + 2.00$$
$$F_{(o-L_e)} = 2.43 \text{ inches, which is noted on the cumulative intake}$$

curve, Figure 22.5.

(i) Depth applied to the furrow plus the extended area.

$$F_e = (1.6041 \ QT_i)/(WL_e)$$
$$= (1.6041 \times 9.2 \times 400)/(3.0 \times 900)$$
$$= 2.19 \text{ inches}$$

(j) On the graph, 2.19 inches was located below the 2.43 inches, Figure 22.5.

(k) A parallel line to the original line. This line is labeled adjusted cumulative intake curve.

(1) Adjusted average weighted depth infiltrated.

$$F_{(o-L_e)adj} = \frac{fo}{2} + f_1 + f_2 \ldots + \frac{fn}{2} \frac{Ls}{(Le)}$$

where

$$f_0 = 2.50, \; f_1 = 2.50, \; f_2 = 2.45, \; f_3 = 2.40,$$
$$f_y = 2.35, \; f_5 = 2.30, \; f_6 = 2.20, \; f_7 = 2.05,$$
$$f_8 = 1.80, \; f_9 = f_n = 0.76$$

(Note: f for station 6 + 50 was not included)

$$L_e = 900$$
$$L_s = 100$$

$$\therefore \; F_{(o-L_e)} = ((2.50/2) + 2.50 + 2.45 + 2.40 + 2.35 + 2.30 + 2.20 + 2.05 + 1.80 + (0.76/2)) \, 100/900$$

$$= 2.19 \text{ inches; this checks with } F_e$$

(m) Minimum depth infiltrated from adjusted cumulative intake curve for $T_{ox \, min} = 321$ min.

$$f_{adj \, min} = 2.15 \text{ inches}$$

(n) Adjusted average depth infiltrated, $F_{(o-L)adj}$, for the actual furrow length.

$$F_{(o-L)adj} = \frac{fo}{2} + f_1 + f_2 \ldots + \frac{fn}{2} \left(\frac{Ls}{L}\right) + \frac{fn + fns}{2} \left(\frac{Lss}{L}\right)$$

where

$$f_0 = 2.50, \; f_1 = 2.50, \; f_2 = 2.45, \; f_3 = 2.40, \; f_4 = 2.35,$$
$$f_5 = 2.30, \; f_6 = f_n = 2.20, \; f_{ns} = 2.15$$

(Note: f_{adj} for 6+50 included)

$$L_s = 100$$
$$L_{ss} = 50$$
$$L = 650$$

$$\therefore \; F_{(o-L)adj} = \frac{2.50}{2} + 2.05 + 2.45 + 2.40 + 2.35 + 2.30 + \frac{2.20}{2} \frac{100}{(650)} + \frac{2.20 + 2.15}{2} \frac{50}{(650)}$$

$$= 2.38 \text{ inches}$$

(o) The depth of irrigation needed (F_n) for this irrigation was 2.5 inches. As an average, only 2.38 inches of water was infiltrated. The field is under irrigated by 0.12 inches.
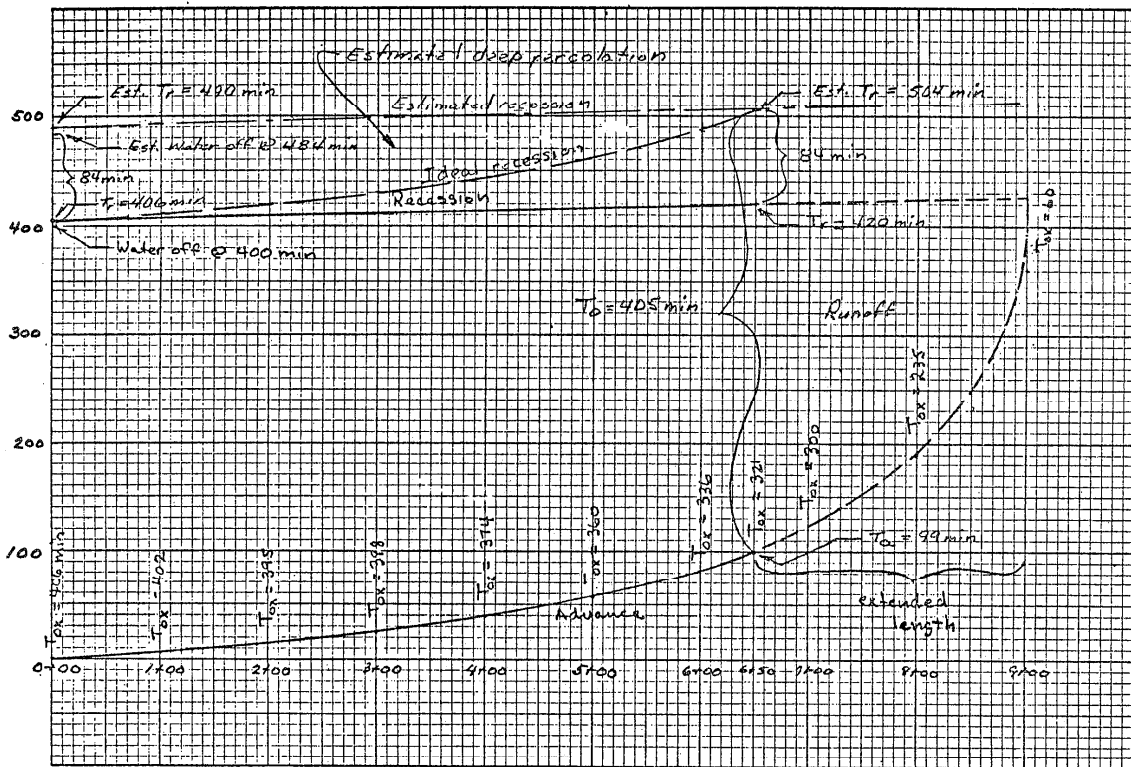
Figure 22.6

(p) Amount of deep percolation

$DP = F_{(o-L)adj} - F_n$

$= 2.38 - 2.50$

$= 0$ inches. There is no deep percolation.

(q) Volume of runoff

$VRO = (QT_i/448.83) - VF_{(o-L)adj}$

$= (9.2 \times (400/60)/448.83) - (2.38)(3.0) 650/43560)$
$= 0.03$ ac-in

(r) Uniformity of application

$DU = (f_{adj\ min}/F_{(o-L)adj}) \ 100$

$= (2.15/2.38) \times 100$
$= 90\%$

(s) Application efficiency

$AE = (F_n/F_g) \ 100$

The application efficiency cannot be determined because of an incomplete irrigation.

(t) Actual application efficiency

$AAE = (DU \times AE)/100$

Application efficiency was not determined for the example.

(u) Required application time (T_i)

The application time needs to be increased because of underirrigation. To estimate the required time, the following procedure can be used.

<u>1</u> Determine the opportunity time required to apply the needed depth of application (F_n) using the adjusted cumulative intake curve as shown in Figure 22.5. For this example, the opportunity time required to apply 2.5 inches is about 405 min.

<u>2</u> Add the required opportunity time to the advance time for the station which has the minimum opportunity time ($T_{ox\ min}$). This gives the recession time at which the water should recede to obtain an adequate depth of application. In this case, $T_{ox\ min}$ occurs at Sta. 6+50 and the advance time (T_a) is 99 min, Figure 22.3. The time at which recession should take place is 504 min (405 + 99) so as to apply 2.5 inches.

<u>3</u> Subtract the actual recession time from the required recession time to obtain the amount by which to increase the inflow time (T_i). In this example, the actual recession time at Sta. 6+50 is 420 min, Figure

22.3. The inflow time should be increased by 84 min (504 - 420). Inflow time in this case is 400 min, Figure 22.3. The required inflow time should be about 480 min (400 + 84).

    4 Figure 22 illustrates the changes which should occur as a result of increasing the inflow time. There will be an increase in runoff.

    5 There does not appear to be a need to change the inflow rate. A 90 percent uniformity of application is considered to be very good and the same should occur with the increased inflow time.

    (4) Recommendations

        (a) Increase the inflow time to about 480 min. An increase in inflow time will increase runoff.

        (b) Leave the stream size the same. There appears to be a good balance between deep percolation and runoff.

        (c) If the objective is to have minimum deep percolation, increase the stream size somewhat. This will reduce the advance time but will increase the amount of runoff.

        (d) Make an additional evaluation after the changes are made.

FURROW IRRIGATION EVALUATION

Farm _____ Field # _____ Date _____

Legal Description _____ By _____

Crop _Corn_ Soil Series _____ AWC _5.0 in_ I$_f$ _0.25_

Furrow width _36 in_ Length _650 ft_ Set Time _400 min_ Stream Size _9.2 gpm_

1. Depth of application needed, F_n = AWC - SWC

   F_n = _5.0_ in - _2.5_ in = _2.5_ inches

2. Gross depth of water applied, F_g = 1.6041 QT_i/WL

   F_g = 1.6041 x _9.2_ gpm x _400_ min/(_3.0_ ft x _650_ ft)

   = _3.03_ inches

3. Minimum opportunity time, $T_{ox\ min}$ = _321_ min @ Sta _6+50_

4. Minimum depth infiltrated, $f_{adj\ min}$ = _2.15_ inches (from adj curve)

5. Is an adequate irrigation obtained? Yes (No) (If $f_{adj\ min}$ > F_n = yes)

6. Ave. depth infiltrated, $F_{(o-L)adj}$ = _2.38_ inches

7. Deep percolation, DP = $F_{(o-L)adj}$ - F_n

   DP = _2.38_ in - _2.50_ in = _-0.12_ inches (Field is under irrigated)

8. Volume of runoff, VRO = (QT_i/448.83) - $VF_{(o-L)adj}$

   VRO = (_9.2_ gpm x (400/60)hrs ÷ 448.83) -

   (_2.38_ in x (_3.0_ ft x _650_ ft/43560)) = _0.03_ ac-in

9. Uniformity of application, DU = $f_{adj\ min}$/$F_{(o-L)adj}$ x 100

   DU = _2.15_ in/ _2.38_ in x 100 = _90_ %

10. Application efficiency, AE = F_n/F_g x 100

    AE = _____ in/_____ in x 100 = _____% Incomplete irrigation

11. Actual application efficiency, AAE = (DU x AE)/100

    AAE = (_____% x _____%)/100 = _____% Incomplete irrigation

12. Required application time, T_i

    T_a = _93_ min @ Sta 6+5.00

    T_L = (time water disappears at Sta. 0+00) - (Time water off)

    T_L = _____ hrs - _____ hrs = _____ (convert to minutes)

    T_o = _405_ min (from adj curve for F_n)

    T_i = _480_ min

13. Recommendations:

    See Paragraph -6-.22.f.(4)

Figure 22.7

MOISTURE DEFICIENCY IN./FT.	Soil Texture Classification				MOISTURE DEFICIENCY IN./FT.
	COARSE (LOAMY SAND)	LIGHT (SANDY LOAM)	MEDIUM (LOAM)	FINE (CLAY LOAM)	
0.0	(field capacity) Leaves wet outline on hand when squeezed.	(field capacity) Leaves wet outline on hand; makes a short ribbon.	(field capacity) Leaves wet outline on hand; will ribbon out about one inch.	(field capacity) Leaves slight moisture on hand when squeezed; will ribbon out about two inches.	0.0
0.2					0.2
0.4	Appears moist; makes a weak ball.	Makes a hard ball.	Forms a plastic ball; slicks when rubbed.	Will slick and ribbon easily.	0.4
0.6	Appears slightly moist. Sticks together slightly. Very dry, loose; flows through fingers. (wilting point)	Makes a good ball.	Forms a hard ball.	Will make a thick ribbon; may slick when rubbed.	0.6
0.8		Makes a weak ball.	Forms a good ball.	Makes a good ball.	0.8
1.0		Will not ball.			1.0
1.2			Forms a weak ball.	Will ball, small clods will flatten out rather than crumble.	1.2
1.4		Wilting point.			1.4
1.6			Small clods crumble fairly easily.	Clods crumble.	1.6
1.8			Small clods are hard (wilting point)		1.8
2.0				Clods are hard, cracked, (wilting point)	2.0

Adapted from "Field Method of Approximating Soil Moisture for Irrigation," by John L. Merriam, Transactions of the A.S.A.E., Vol. 3, No. 1, 1960.
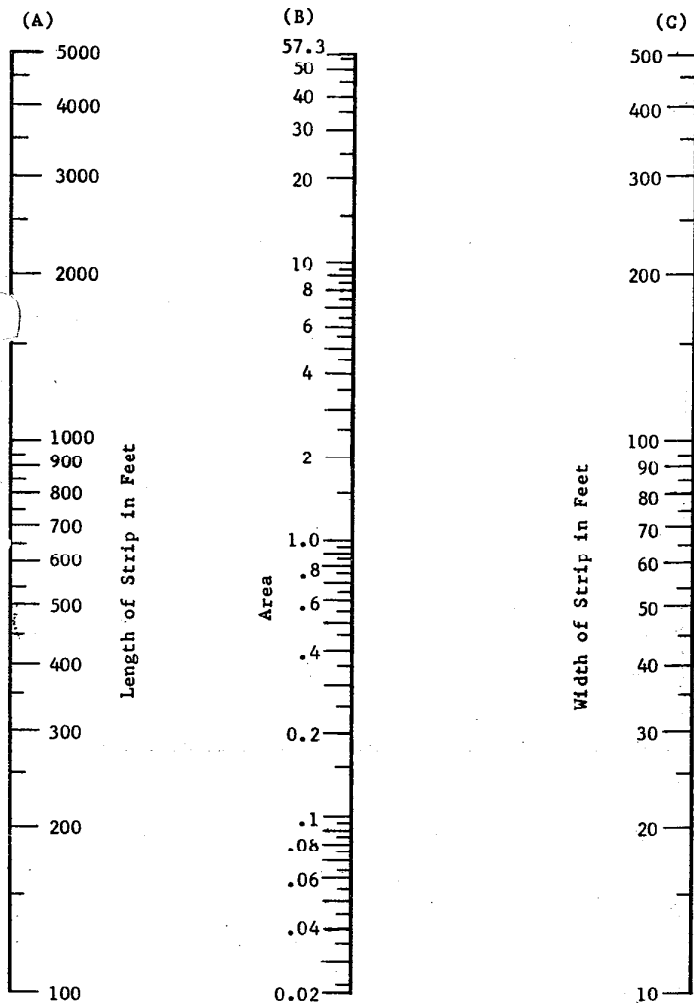
TABLE 10.1-A Soil Moisture and Appearance Chart

WATER APPLICATION RATE

(A)

(B)

(C)

Gallons per Minute Onto Strip

5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100

Application Rate Inches Per Hour

10
8
6
5
4
3
2
1
.8
.6
.5
.4
.3
.2
.1

Area of Strip in Acres

.2
.3
.4
.5
.6
.8
1
2
3
4
5
6.0
8.0
10.0
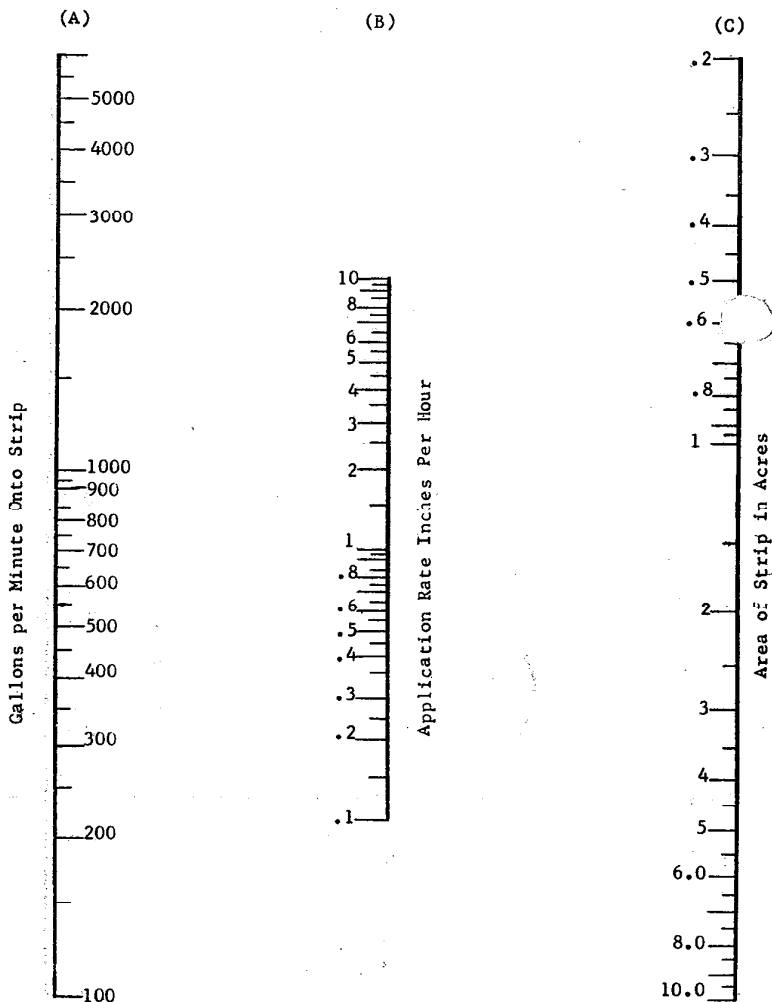
Sample Solution: To obtain the Application Rate on
a Border Strip 2 Acres in Size With a 900 gpm
Stream, Join a Line from 900 gpm on Scale (A) to 2
on Scale (C) and read 1" per Hour on Scale (B).

AREAS OF STRIPS

(A)	(B)	(C)
5000	57.3	500
	50	
4000	40	400
	30	
3000	20	300
2000	10	200
	8	
	6	
	4	
1000	2	100
900		90
800		80
700	1.0	70
600	.8	60
500	.6	50
400	.4	40
300	0.2	30
200	.1	20
	.08	
	.06	
	.04	
100	0.02	10

Length of Strip in Feet — Area — Width of Strip in Feet

Sample Solution: To Obtain the Area of a Strip
1450 Ft. Long and 45 Ft. Wide, Join a Line From
1450 in Scale (A) to 45 in Scale (C) and Read
1.5 Acres in Scale (B).